

PHYSIOLOGICAL AND SENSORY ASPECTS OF MATURATION, RIPENING,
AND POSHTARVEST CHILLING OF FRESH MARKET MELTING- AND
NONMELTING-FLESH PEACH FRUIT

By

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To Celeste

To my family in Argentina

In memory of Carolina

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A study was conducted to detect differences in sensory and chemical characteristics of melting- (MF) and nonmelting-flesh (NMF) peach genotypes intended for the fresh market. Sensory results showed that the NMF fruit ('Oro A' and FL 86-28C) were rated as "harder," less "juicy," and more "rubbery" than their MF (FL 90-20 and 'TropicBeauty') counterparts. A principal component analysis of the sensory data showed a clear distinction between the textural aspects of MF and NMF fruit, but not between their flavor aspects. Likewise, chemical analysis showed that while differences in pH, titratable acidity, and soluble solids were detected among the four genotypes, no consistent grouping could be made based on the MF/NMF nature of the fruit.

Individual linear correlations were conducted between each genotype's fruit attributes at harvest and their respective sensory first principal components (PC1s) after storage and ripening. Following are the three attributes that best correlated with PC1, and thus, they are the most promising maturity indices; for FL 90-20: ground color (GC) hue, GC L, and cheek (CH) texture; for 'TropicBeauty': peel L, CH texture, and blossom-end (BE) texture; for 'Oro A': CH texture, BE texture, and CH chroma; for 86-28C: BE texture, CH hue, and CH texture. BE and CH texture were highly correlated with PC1s in both MF and NMF genotypes, thus highlighting texture as a potential maturity index.

A study to compare the response to postharvest chilling of MF (FL 90-20, FL 90-21, and FL 91-16) and NMF ('Oro A', FL 90-35C, and FL 90-47C) genotypes revealed that while all MF genotypes developed symptoms of mealiness in 1 or 2 weeks, the NMF genotypes did not show this disorder. Mealiness in the MF genotypes was apparently related to an increase in cell separation. Histologically, chilling of MF fruit brought about an impressive expansion of the intercellular spaces in mesocarp tissue, but did not affect NMF fruit. Sensory evaluation to assess chilling injury showed that while chilled MF fruit were scored as significantly more "mealy," less "sweet," and with less "peach character" than non-chilled fruit, no major differences in those notes occurred between chilled and non-chilled NMF fruit. On the other hand, chilled fruit of both MF and NMF types were scored as significantly less "juicy" and "harder" than non-chilled fruit. An analysis of aroma volatiles revealed that the most relevant changes occurring in both MF and NMF fruit with chilling were an increase in (E)-2-hexenal and a decrease in the levels of γ - and δ - decalactones. However, the extent of the drop in both decalactones was significantly less in NMF than MF fruit.

CHAPTER 1 INTRODUCTION

Prunus germplasm is varied and consists of numerous species and types within the species. The heterogeneous genetic base of the peach--*Prunus persica* (L.)--is displayed in the great phenotypic variability exhibited by the fruit. According to appearance and sensory characteristics, peach fruit can be classified as round, flat or beaked; pubescent or smooth-skinned; freestone or clingstone; white, yellow or red fleshed; sweet, sour or astringent; and melting- (MF) or nonmelting-fleshed (NMF) (Rom, 1988).

The main distinction between MF and NMF fruit is that the latter lack the rapid loss of firmness, known as “melting of the fruit,” characteristic of the final stages of ripening of MF fruit (Lester et al., 1996). Based on this distinction, fruit of these two types have traditionally been channeled to either the fresh market (MF) or the canning industry (NMF).

When MF peaches are left to ripen on the tree in order to achieve maximum quality, they show a propensity to mechanical damage and decay during shipping and handling, that results in a reduced postharvest life (Robertson et al., 1992a). Unlike MF peaches, NMF cultivars are traditionally grown for canning purposes due to the fruit's tolerance to the high-temperature retort treatment, which can compromise fruit integrity. These NMF cultivars, however, lack the red coloration, acidity, and aroma of commonly grown dessert-type MF fruit.

An important goal for current breeding programs is to develop NMF peaches, but with fresh-market sensory characteristics. The purpose is to develop fruit that are able to attain maximum flavor on the tree, yet maintain sufficient firmness to allow distribution through normal marketing channels (Sherman et al., 1990).

While sensory changes occurring during ripening of MF peaches have been thoroughly studied (Delwiche and Baumgardner, 1983; Chapman et al., 1991; Robertson et al., 1992b), NMF fruit intended for the fresh market have not received the same attention. Similarly, no maturity indices have been identified for these newer NMF genotypes. The early blushing and slow-softening characteristic of some of these newer genotypes poses the question of whether ground-color or firmness measurements, two common indicators of maturity for MF peaches, can have any predictive value of the NMF fruit's final quality assessment.

Even though these newer genotypes may effectively address the problem of excessive softening and mechanical damage, their suitability for low-temperature storage remains unknown. Although refrigeration is considered an indispensable need for minimizing physiological deterioration, decay, and moisture loss in peaches, low-temperature storage is associated with a serious physiological disorder known as internal breakdown or chilling injury (Ben-Arie et al., 1970; Anderson, 1975). Based on the detrimental impact that this disorder is having on the fresh market peach industry (Bruhn, 1994; Stockwin, 1996), it is critical to assess the tolerance that these newer genotypes have to chilling injury.

CHAPTER 2 LITERATURE REVIEW

Introduction

The peach, *Prunus persica* (L.) Batsch, is thought to have originated in China, in an area near the city of Xian. The species *persica* is but one of about 250 species within the genus *Prunus* (Rom, 1988a). The smooth-skinned nectarine also belongs to this species, but has been categorized under the variety name *nectarina* (LaRue, 1989)

The peach is widely distributed between the 30°- 40° latitudes (Rom, 1988a) and is successfully grown in the United States, with a total harvested area of 71,012 hectares in 1993. The production volume for that year reached 1206 million kg, with approximately half of this volume aimed for fresh consumption and half for processing (USDA, 1994).

Fruit Development

The peach fruit originates from a perfect (i.e. with both sexes present) and complete (i.e. having calyx, corolla, androecium and gynoecium) flower. Following pollination and fertilization, the perianth is shed and the ovary continues to enlarge. The fruitlet develops into a drupe, with a thin epicarp, a fleshy mesocarp and a stony endocarp containing the seed (Rom, 1988b). The peach, as well as other drupes, shows a double-sigmoid growth curve, with three distinct phases of growth: (I) cell division and expansion, (II) slow growth and lignification of the endocarp, and (III) cell expansion in the mesocarp tissue (Connors, 1919). Although Masia et al. (1992) acknowledge the

double-sigmoid nature of the growth curve, these authors divide the process into four growth stages by recognizing each increase or decrease in the relative growth rate as a distinct stage. The duration of each growth stage depends on variety, climatic conditions, and cultural practices. From a postharvest standpoint, interest in stage III is greatest, since maturation and ripening occur during this stage (Kader and Mitchell, 1989).

Compositional Changes During Maturation and Ripening

The composition of young developing peaches is such that the fruit are practically inedible. As time elapses, the flesh cells enlarge and the fruit sugars, acids, tannins, etc., undergo major modifications that lead to an overhaul of their eating quality (Kader and Mitchell, 1989; Masia et al., 1992). Soluble solids in mature peaches and nectarines should be in excess of 10% for acceptable quality (Brady, 1993). A rise in the concentration of soluble solids has been reported during fruit development and ripening (Luh and Phithakpol, 1972; Kader et al., 1982a; Byrne et al., 1991; Robertson et al., 1992a). Working with clingstone genotypes, however, other authors found no significant increases in soluble solids with advancing maturity in the cultivar 'Allgold' and the selection A-219 (Brooks et al., 1993), and in selections L9-A47-33 and FLA 9-20C (Robertson et al., 1993).

Typically, 65 to 80% of the soluble solids in mature peaches are sugars, with sucrose being predominant (70% of total sugars) over glucose (15% of total sugars), fructose (10% of total sugars) and sorbitol (5% of total sugars) (Kader et al., 1982a.; Kader and Mitchell, 1989; Moriguchi et al., 1990). Some discrepancy exists in reports concerning the concentration of the two reducing sugars, as Byrne et al. (1991) found that

in twelve high-acid genotypes, the levels of fructose were much higher than those of glucose. The relative amounts of these two sugars play a role in defining the fruit's ultimate taste, since fructose is sweeter than sucrose, which is in turn sweeter than glucose (Whistler, 1985).

Young peach fruit store some carbon as starch, but this is used before the fruit enters growth stage three and thus starch to sugar conversions are not involved in peach ripening (Brady, 1993). The large increase in the concentration of sucrose that occurs during the latter phases of fruit development is accounted for by an increase in activity of an important sucrose-synthesizing enzyme, sucrose synthase. Slight increases in glucose and fructose, on the other hand, are attributed to the greater activity of two enzymes involved in their metabolism, sorbitol oxidase and acid invertase (Moriguchi et al., 1990). Sorbitol levels decrease early in the maturation process, but remain steady throughout ripening (Brooks et al., 1993).

Fruit acids are the other major components that change during peach ripening. Organic acids in peaches reach a maximum during maturation and decrease as the fruit ripens (Ryugo and Davis, 1958; Luh and Phithakpol, 1972; Boggess, et al., 1974; Byrne et al., 1991; Robertson et al., 1992a, 1993; Brooks et al., 1993). During ripening, acids are respired or converted into sugars (Wills et al., 1981; Haard, 1985; Kays, 1991).

Malic acid is the predominant organic acid in peaches (50-60% of total acids), followed by citric (20-25% of total acids) and quinic (20-25% of total acids), and occasionally by lower levels of fumaric, oxalic, and succinic acids (Lill et al., 1989; Byrne et al., 1991). Titrable acidity is a customary way to report changes in the levels of organic

acids; however, it should be noted that lactones, which are major flavor components in peaches, also account for a portion of the titrable acidity (Romani and Jennings, 1971).

Not as drastic as the changes in titrable acidity, the flesh pH has been reported to increase throughout the ripening process in peaches (Bogges, et al., 1974; Kader et al., 1982). Conversely, no clear trend in the flesh pH was found in a study of fifteen peach cultivars before and after ripening off the plant (Robertson et al., 1990).

A commonly measured parameter of a fruit's gustatory aspect is the ratio of soluble solids to titratable acidity (SS:TA) (Sadler, 1994). Besides determining the degree of sourness, acids affect the perception of sweetness (Kader and Mitchell, 1989; Brooks et al, 1993). The SS:TA ratio increases as peaches mature and ripen (Kader et al., 1982a; Byrne et al., 1991; Robertson et al., 1992a, 1993; Brooks et al., 1993).

Color Changes During Maturation and Ripening

Pigments are also affected during peach ripening. Chlorophyll, present both in the peel and flesh, reaches a maximum level at the end of the first stage of fruit growth and decreases rapidly afterwards (Lessertois and Moneger, 1978; Amoros et al., 1989). The anthocyanin cyanidin-3-monoglucoside is the main pigment responsible for the red coloration that develops in the peel of peaches upon ripening (Hsia et al., 1965). Xanthophylls, on the other hand, are the most important carotenoids causing the yellow coloration (Romani and Jennings, 1971). An increase in total carotenoids with maturity was reported for the variety 'Baby Gold 6' (Amoros et al., 1989) as well as for eight canning selections (Kader et al., 1982a). Katayama (1971) noted that the increase in

carotenoids occurred when the peaches turned from green to yellow, with negligible changes occurring afterwards, as the fruit ripened and senesced.

Since the development of anthocyanins in the peel (blush) is so heavily dependent on the fruit's exposure to light, it is changes in the ground (background) skin color that often reflect a fruit's stage of maturity (Delwiche and Baumgardner, 1985; Kader and Mitchell, 1989).

Changes in a fruit's color are effectively monitored using the CIELAB method. This method provides a system of numerical coordinates to locate individual colors in a three-dimensional geometric representation of the colors in a given color gamut. The system relies on three measurements: 'L' or lightness coefficient (ranges from black=0 to white=100), 'a' coordinate (positive for red and negative for green), and 'b' coordinate (positive for yellow and negative for blue). For an appropriate color identification the lightness coefficient 'L' should be accompanied by the corresponding mathematical manipulations of the 'a' and 'b' coordinates: hue angle and chroma. The hue is an angle from 0° to 360° and has reference points of 0°=red, 90°=yellow, 180°=green, and 270°=blue. The chroma, on the other hand, is a measure of the color's intensity or purity and reflects the departure of a color from gray for a given hue angle (Francis, 1980; McGuire, 1992; Voss, 1992).

A comprehensive CIE color evaluation of thirteen peach varieties conducted by Delwiche and Baumgardner (1983) revealed that differences in ground color for different maturities occurred primarily in the 'a' coordinate, which increased as maturation advanced. Slight increases in the 'b' coordinate of the ground color of 'Baby Gold 6' fruit were observed by Amoros et al. (1989) during the first 70 days after fruit set. Afterwards,

it was the 'a' coordinate that increased drastically as the fruit developed red pigmentation in the skin. Significant increases in the 'a' value and decreases in the hue angle of the skin ground color were found upon ripening of yellow- as well as white-fleshed peach varieties. Differences in ground color between the two types were evidenced by lower 'b' values for white-fleshed cultivars (Robertson et al., 1990). When Byrne et al. (1991) related firmness of twelve peach cultivars to their respective Hunter CIE 'a' values, they found that the skin and flesh 'a' values increased as flesh firmness decreased. Similar measurements of the ground color conducted on three NMF genotypes (FL 9-20C, L9-A47-33, and 'Babygold 7') showed dramatic increases in 'a' values, moderate decreases in 'L' and hue angles, and an erratic behavior for the 'b' value with maturity (Robertson et al., 1992a, 1993). A study of flesh color changes occurring during maturation of the NMF canning cultivars 'Babygold 5' and 'Babygold 7' revealed significant increases in the 'a' value as well as in the hue angle, and more inconspicuous declines in the 'L' and the 'b' value (Fuleki and Cook, 1975).

Peach Aroma

The aroma of fruits results from the interplay of volatile compounds, whose presence vary according to pre- and postharvest factors such as cultivar, maturity, and storage conditions (Heath and Reineccius, 1986). The definition of peach aroma involves a large number of volatile compounds, with some authors having found up to 110 components, including alcohols, aldehydes, alkanes, esters, ketones, sulfur-containing compounds and aromatic hydrocarbons (Narain et al., 1990). A comparative study conducted on a number of cultivars concluded that the major peach aroma compounds

were hexanal, (E)-2-hexenal, benzaldehyde, linalool, 6-pentyl- α -pyrone, γ - and δ -decalactones, and hexadecanoic acid (Horvat et al., 1990).

Cultivar differences generally result from quantitative rather than qualitative changes in a fruit's aromatic composition (Heath and Reineccius, 1986). Hexanal and (E)-2-hexenal are among the aroma compounds that vary most among peach cultivars (Horvat et al., 1990). Lactones, on the other hand, are not as intensely regulated by a peach cultivar's genetic make-up (Horvat et al., 1990). In cling peaches traditionally used by the canning industry, Brecht et al. (1982) found that cultivar selection had a pronounced effect on the quality of the final product, including the production of off-flavors.

Profound modifications occur in the peach aromatic profile as the fruit undergoes ripening (Do et al., 1969; Meredith et al., 1989; Chapman et al., 1991). When Do et al. (1969) studied the influence of maturity on peach flavor, they found that lactones, which have a critical involvement in peach aroma, increased as fruit maturity progressed on the tree. Fruit that were ripened off the tree (21 C and 35% relative humidity), however, contained very small amounts of γ -lactone and were lacking in α - and δ - lactones. Similarly, benzaldehyde and total esters in fruit ripened off the tree reached only 20% and 50% of the respective concentrations found in the tree-ripened counterparts. Meredith et al. (1989) reported that the compounds hexenal, hexanol, linalool, nonanal, and δ -decalactone were only detected in advanced stages of maturity corresponding to maturity color chip 6 (Delwich and Baumgardner, 1985). Chapman et al. (1991) found that the contents of linalool, benzaldehyde and γ - and δ - decalactone in peaches increased significantly during sequential harvests. Volatile production at three different stages of

maturity was shown to differ, even when firmness, color and respiration rate were similar at the time of volatile measurement for all three stages (Lim and Romani, 1963).

The storage environment has also been linked to changes in specific aroma volatiles of a number of fruit crops (Heath and Reineccius, 1986). The peach volatiles hexanal, trans-2-hexanal, and linalool decreased from the initial concentration at harvest when fruit were stored for up to 6 weeks at 0 C and subsequently ripened for 7 days at 20 C. However, the levels of γ - and δ -decalactone in these fruit were comparable to those achieved on the tree (Robertson et al., 1990).

Climacteric

Along with sensory and nutritional changes, peaches exhibit a rise in their respiratory activity during ripening (Lim and Romani, 1963; Looney et al., 1974; Amoros et al., 1989). This rise follows the typical climacteric pattern (Looney et al., 1974; Lill et al., 1989). Relative to other horticultural commodities, peaches have a moderate respiration rate during ripening, with levels ranging from 59 to 102 mg CO₂ kg⁻¹ hr⁻¹ at 20 C (Hardenburg et al., 1986; Kader and Mitchell, 1989). Variations in the rate of respiration have been observed for different varieties, maturities or preharvest factors, such as climatic conditions or cultural practices (Kader and Mitchell, 1989).

A climacteric surge in the production of ethylene is also observed during the ripening of peaches (Looney et al., 1974; Miller et al., 1988; Amoros et al., 1989; Tonutti et al., 1991) and nectarines (Brecht and Kader, 1984a, 1984b). The magnitude of the rise is such that it can represent a 10-fold increase from the preclimacteric level (Miller et al., 1988). According to Amoros et al. (1989), the peaks of ethylene and carbon dioxide in

peaches occur within the same time frame. The rate of ethylene production in peaches ranges from 0.1 to 140 $\mu\text{l kg}^{-1} \text{ hr}^{-1}$ at 20 C (Kader and Mitchell, 1989). The rate of ethylene production is influenced by factors such as (1) temperature: ethylene production increases with a rise in temperature (Kader and Mitchell, 1989); (2) atmospheric composition: while reduced oxygen levels reduce ethylene production (Kader et al., 1982b; Ke et al., 1991), elevated carbon dioxide concentrations may either increase or decrease ethylene production (Kader et al., 1982b; Kader and Mitchell, 1989; Kubo et al., 1990), and (3) varieties: different genotypes vary widely in their rates of ethylene production (Kader and Mitchell, 1989). It has been claimed that, in peaches, the biological basis for differences in flesh firmness is related to differences in capacity for ethylene production (El-Agamy et al., 1981; Biggs et al., 1982). In nectarines, Brecht and Kader (1984c, 1984d) reported a relationship between the slow-ripening trait found in four selections and their inability to produce levels of ethylene found in normally-ripening varieties.

Textural Characteristics of Peaches

The peach is particularly heterogeneous in its genome and has adapted to multiple growing conditions. This flexibility, which is manifested in the great phenotypic variability exhibited by the fruit, has led pomologists to classify cultivars based on the appearance and sensory characteristics of the fruit as: round, flat or beaked; pubescent or smooth-skinned; freestone or clingstone; white-, yellow- or red-fleshed; sweet, sour or astringent; and melting- (MF) or nonmelting-fleshed (NMF) (Rom, 1988).

MF and NMF fruit are naturally occurring biotypes which differ conspicuously in the way in which they change their texture during ripening. The loss of firmness in MF fruit is gradual in the beginning of the ripening process and rapid during the final stages. NMF fruit, on the other hand, lack the final melting phase of softening and remain firm at the fully ripe stage (Lester et al., 1996). The comparatively higher firmness exhibited by NMF fruit has made them specially suitable for the canning process, due to their tolerance to the high retort temperatures (Robertson et al., 1993).

The softening process in peaches is the subject of intense study due to its relevance to methods of fruit production, harvest, storage, and sale (Lester et al., 1996). In a recent survey of five major market areas in the United States, consumers cited fruit firmness as their number one concern regarding peach quality (Bruhn, 1994). While “tree ripe” fruit are preferred among consumers and constitute a new target for a sector of the peach industry (Chapman, 1989), textural limitations make these fruit more susceptible to damage losses (Vergano et al., 1995). When MF peaches, which are customarily grown for the fresh market, are left to ripen on the tree in order to achieve maximum sensory quality, they show a propensity to mechanical damage and decay and have an overall short postharvest life (Robertson et al, 1992a). Unlike MF peaches, NMF cultivars are traditionally grown for canning purposes and, while they remain firm during ripening, they typically lack the red coloration, acidity, and aroma of commonly grown dessert-type MF cultivars (Sherman et al., 1990).

Two different approaches to the production and handling of “tree-ripe” peaches with minimal injury are currently under study. One evaluates the possibility of minimizing damage to “tree ripe” MF fruit by modifying package design or handling practices

(Brusewitz et al., 1991; Vergano et al., 1992, 1995; Maness et al., 1995). The other involves the breeding of fruit with NMF that have a natural higher tolerance to mechanical damage, along with improved sensory characteristics that make them suitable for the fresh market (Sherman et al., 1990).

The Physiological Basis for Nonmelting Flesh

The main distinction between MF and NMF fruit lies in the reduced capability of the latter to degrade its cell walls (Postlmayr et al., 1956; Shewfelt, 1965). Studies on the cell wall degradation of MF peaches have revealed that, while substantial decreases in the pectin and hemicellulose fractions occur during fruit softening, the cellulose level remains almost unaltered from its pre-ripening stage (Bouranis and Niavis, 1992).

Due to the central role that pectins play in the textural changes of ripening fruit, most studies of the peach cell wall have concentrated on the pectin fraction and related enzymes (Ben-Arie et al., 1989, Fishman et al., 1993, Robertson et al., 1993; Lester et al., 1994, 1996). Pectin solubilization, which has been shown to increase during normal ripening of MF peaches (Shewfelt et al., 1971), remains low during ripening of NMF peaches (Postlmayr et al., 1956; Shewfelt, 1965; Fishman et al., 1993, Robertson et al., 1993). This behavior is explained by the fact that while MF peaches have both endo- and exo-polygalacturonase (PG), NMF peaches have reduced levels of the endo- form of the enzyme (Pressey and Avants, 1978). Exo-PG attacks the pectin molecule at the nonreducing end, whereas endo-PG is able to cleave internal α -1,4-glycosidic bonds. Comparatively, exo-PG has a more limited effect on pectin degradation than endo-PG (Kays, 1991).

In MF fruit, endo-PG activity increased with the advance of softening during ripening (Orr and Brady, 1993). In NMF fruit, however, no changes in the pectin molecule can be attributed to the activity of endo-PG (Fishman et al., 1993). The link between endo-PG and the MF locus seems unequivocal (Lester et al., 1996). In two pieces of work (Lester et al., 1994; Lester et al., 1996), the genetic disturbance for normal endo-PG activity associated with the NMF trait could be traced to two levels depending on the cultivar. In the cultivar 'Carolyn', the transcription of the endo-PG gene occurred normally, but the small size of the RNA transcript seemed to reflect a sequence aberration that affected translation and/or enzyme production (Lester et al., 1994, 1996). In the cultivar 'Fla. 9-20', however, a complete deletion of the endo-PG gene was documented. According to these authors, it is reasonable to expect different sources for the NMF trait, as it seems to have existed for many hundreds of years (Lester et al., 1996).

Determining Harvest Maturity

An understanding of the terminology related to the maturation process is of utmost importance in postharvest physiology. The term "physiological maturity" is distinguished from the term "horticultural maturity". While the first indicates the state at which a plant organ can continue ontogeny even when detached from the plant, the latter refers to the stage at which it possesses the prerequisites for utilization by consumers for a particular purpose (Watada et al., 1984). The concept of horticultural maturity implies the utilization of a measurable point at which the commodity should be harvested for a particular purpose. A "measurement or measurements that can be used to determine whether a commodity is mature" is known as a maturity index (Reid, 1992). According to

Crisosto (1994) a maturity index must address two basic issues: it must ensure an acceptable eating quality at the same time that it contemplates a long storage life for the commodity.

Maturity indices constitute an important aspect of trade regulations, marketing strategies and the efficient use of labor and resources (Crisosto, 1994). An ideal maturity index should meet the following criteria: simple to measure, objective, applicable to all growing sites and years, and, preferably, nondestructive (Reid, 1992). Maturity indices for various horticultural crops have relied on different features of the commodity, like duration of development, size, density, color, firmness, etc., which provide an adequate estimate of maturity (Shewfelt, 1993).

The search for maturity indices for different peach varieties for the fresh market has been extensive, but the approaches for their determination have differed considerably. A number of researchers focused on the correlation that different physicochemical parameters of the fruit had among each other or on the progression of these parameters with advancing maturity. Sims and Comin (1963) separated 'Halehaven' fruit at harvest into eight maturity groups based on their firmness and correlated this trait with other physicochemical aspects. A high correlation was found between firmness and ground and flesh color. Salunkhe et al. (1968) studied the progress of various characteristics of the fruit during ripening of 'Redhaven' peaches. Firmness and the ratio of soluble solids to acidity were concluded to be the best maturity indices for this cultivar. A study on the changes in ground color during maturation and ripening was conducted on three peach varieties ('Redhaven', 'Redglobe' and 'Rio Oso Gem'). A high correlation between the measured 'a' value obtained from a tristimulus colorimeter and a set of color references

proved the feasibility of using color references as maturity indices for the varieties studied (Delwiche and Baumgardner, 1985). In order to obtain a range of maturities of the peach cultivars 'Red Haven' and 'Marqueen', Luchsinger and Walsh (1993) conducted multiple harvests spaced at 4-day intervals. One day after harvest and 7 days after ripening off the tree, fruit were measured for their firmness, ground color and ethylene production. After studying the correlation between these factors, it was concluded that ground color was an effective index for maturity.

Alternatively, other authors considered the relationship of various physicochemical aspects of the fruit at harvest with the sensory quality of the ripe fruit. When Rood (1957) correlated a number of physicochemical fruit aspects at harvest to the acceptability of the ripe fruit as assessed by a 5-member sensory panel, flesh firmness was found to be the best maturity indicator for the four cultivars under study ('Redhaven', 'July Elberta', 'Elberta', 'J.H. Hale', and 'Rio Oso Gem'). Delwiche and Baumgardner (1983) conducted a comprehensive study of peach flesh firmness and ground color at harvest along with postripening aspects, including acceptability as assessed by a 10-member taste panel. Since ground color proved to be a better indicator of maturity than firmness, specific color coordinates obtained from a tristimulus colorimeter were determined as thresholds for harvesting the thirteen cultivars under study. Also using standard color references, Meredith et al. (1989) sorted 'Harvester' peaches into six color grades and a 14-member taste panel judged the fruit for acceptability both at harvest and after ripening. Two different threshold color standards were defined for peaches intended for consumption right after harvest and those to be ripened off the plant. The correlation between physicochemical aspects and individual sensory notes of 'Loring' peaches, as

defined by descriptive sensory evaluation, was studied by Robertson et al. (1992b). Grade five, as determined by using Clemson University Color Chips (Delwiche and Baumgardner, 1985), was judged to be the threshold for harvesting the fruit. A detailed analysis of the relationship between tristimulus color measurements and visual hedonic color evaluations of thirty- six peach cultivars was conducted by Baughner et al. (1995). Hue angle of the blushed fruit surface was found to be the best predictor of visual rating.

In California, the leading peach producing state in the United States, harvest date for most cultivars is determined by ground color changes from green to yellow. The three tier maturity system includes (1) US-Mature, (2) Well-Mature, and (3) Tree Ripe. For a shipment to qualify as Tree Ripe, at least 90% of the fruit must fall in the category of California Well Mature, which is reached when at least 90% of the fruit's aggregate surface area has met the color guide established for the cultivar (Marketing Order 917, 1996).

Newer technologies such as delayed light emission (DLE) and microwave permittivity are emerging as potential means of detecting maturity in peaches. Forbus and Dull (1990) conducted a study to determine the relationship between DLE and physicochemical properties for a range of visually assessed maturity grades. The results showed that DLE was highly correlated with maturity stage for the three cultivars studied ('Keystone', 'Nectar' and 'Loring'). A detailed analysis of various chemical components in 'Majestic' peach fruit that were separated into maturity categories based on DLE was conducted by Chapman et al. (1991). It was concluded that sucrose and quinic acid levels, malic/citric acid ratio, and the concentration of major volatiles were useful indices for determining maturity.

A rapid sensing technique based on the changes in microwave permittivity was tested on three peach cultivars ('Dixired', 'Redhaven' and 'Windblow') collected during three sequential harvests (Nelson et al., 1994). Although experimental permittivity measurements proved to correlate well with maturity, this method is more suited to on-line processes, such as sorting and grading, than to harvesting decisions.

In peaches, as well as in most other climacteric fruits, there is a pronounced difference between fruit that are considered to have reached maturity and those that have reached maximum edible quality (Reid, 1992). Commercially, peaches are generally harvested at a mature-firm stage and further ripened off the tree before they are sold to the final consumer (Kader and Mitchell, 1989). It is during ripening when fruits develop their "aesthetic and/or food quality characteristics, as evidenced by changes in composition, color, texture or other sensory attributes" (Watada et al., 1984).

Significance and Interpretation of Sensory Evaluation Results

Although sensory evaluation was included as a part of the procedure to determine maturity indices in the studies conducted by Rood (1957), Delwiche and Baumgardner (1983), and Meredith et al. (1989), the use of a few trained panelists for the determination of the acceptability of a food product, as used in those studies, has been questioned (Meilgaard et al., 1991; Conner and Booth, 1992; Stone and Sidel, 1993). While an appropriate way of measuring acceptance is by means of consumer panels, this type of evaluation requires a large number of panelists and can render information of dubious quantitative significance. Furthermore, the affective dimension of foods, that is the degree of like or dislike for particular items, depends not only on basic sensory characteristics but

also on the particular situations under which the food is consumed (Schutz, 1988; Meilgaard et al., 1991).

Foods are complex stimuli toward which consumers have a variety of attitudes (Schutz, 1988). The quality of foods has been described as the composite of those characteristics that differentiate individual units of a product and have significance in determining the degree of acceptability of that unit by the consumer (Kramer and Twigg, 1970). Descriptive sensory evaluation is a very thorough approach that addresses the complexity of food systems by taking into account as many of a food's attributes (also known as sensory notes) as possible. The interpretation of descriptive sensory evaluation is often assisted by multivariate statistical procedures, such as principal component analysis (Resurreccion, 1988; Meilgaard et al., 1991; Lyon et al., 1993; Pino et al., 1993). The use of principal component analysis allows for the transformation of a set of variables, such as the sensory notes, into a substantially smaller set of uncorrelated variables (principal components). Besides aiding in data interpretation, principal component analysis is able to reduce the magnitude of the error or noise that is often associated with descriptive sensory evaluation. Each principal component is a linear combination of the original variables (sensory notes), which are assigned coefficients or weights (factor loadings) that represent the relative importance of these variables in the definition of each principal component. Although several principal components can be extracted from the original data set, it is the first few which usually explain the majority of the variability, with the first principal component accounting for the greatest proportion, followed by the second, and the third, and so on (Piggott and Sharman, 1986; Resurreccion, 1988; Duntzman, 1989; Bryant and Yarnold, 1995).

The use of multivariate statistics in food-related research has involved products such as tomatoes (Resurreccion and Shewfelt, 1985), cabbage (Martens, 1985), peaches (Lyon, 1993) and grapefruit juice (Pino et al., 1993).

Fruit Quality as Related to Storage Temperature

While the use of newer NMF genotypes and improved package designs or handling practices promise to minimize softening and its effects in peaches (Sherman et al., 1990; Vergano et al., 1992), other aspects of fruit quality still need to be addressed (Bruhn, 1994). Physical injury, decay, and moisture loss are important factors involved in the deterioration of the fruit's final quality (Mitchell and Kader, 1989). The use of low temperatures is an effective approach to minimize all those undesirable effects in peaches (Mitchell and Kader, 1989). The significance of precooling and refrigerated storage in reducing bruising and impact parameters such as contact time and peak force, have been documented (O'Brien et al., 1978; Mitchell, 1988; Brusewitz et al., 1992). Refrigerated storage is also so critical to the management of postharvest diseases that all other treatments can be considered as 'supplements' to refrigeration. Low temperature effects on the retardation of decay are dual; not only is the growth of most peach pathogens delayed at reduced temperatures, but also refrigeration retards fruit senescence and, therefore, reduces susceptibility to microbial invasion (Sommer, 1989). Moisture loss is another problem that is minimized by the use of refrigerated storage. Peaches are severely affected by the loss of internal moisture, with visual shrivelling occurring when weight loss reaches 3 to 5% of the fruit's initial weight (Wells, 1962; Mitchell and Kader, 1989). Hruscka (1977) found that, under low humidity conditions, the weight decrease

attributable to moisture loss in peaches was much higher than that observed in nectarines, apples, pears, and persimmons.

Optimum storage conditions for both MF peaches and nectarines have been established as -0.5 to 0 C and 90-95% relative humidity (Hardenburg et al., 1986).

Chilling Injury

Although low-temperature handling and storage of peaches is a critical postharvest requirement (Hardenburg et al., 1986), not all metabolic activities are reduced to the same extent upon cooling, with some even being promoted at those low temperatures (Wills et al., 1981). While it is admitted that lower temperatures result in a better storage life of peaches, it has also been proven that storage in the temperature range of 2.2 to 7.7 C leads to the development of the physiological disorder known as chilling injury (Harding and Haller, 1932, 1934; Ben-Arie et al., 1970; Anderson, 1975; Crisosto et al., 1996).

Although variable among peach varieties, classic symptoms of chilling injury include flesh browning; a dry texture resembling corn meal (mealiness), wool (wooliness), or leather (leatheriness); failure to ripen and/or develop normal flesh color, lack of characteristic aroma, translucency of the flesh; and, indirectly, a decreased resistance to the invasion of pathogens (Mitchell and Kader, 1989). The incidence of chilling injury in commercial handling of peaches has reached a magnitude that, based on the results of a detailed market study, caused Bruhn (1994) to suggest that “the industry should explore the market potential for premium *guaranteed* high quality fruit which has met specific maturity standards and been monitored during shipment and storage with time/temperature indicators.”

One of the first accounts of chilling injury in commercial peach varieties ('Carman', 'Belle of Georgia', 'Elberta', and 'J.H. Hale') dates from 1932 (Harding and Haller). These authors observed that, although low temperatures were needed to maintain fruit softening and decay at a minimum, temperatures between 2.2 and 4.4 C resulted in what they described as internal breakdown (water-soaked areas around the pit, flesh discoloration, and mealiness). Even before internal breakdown became apparent, dessert quality, as judged by tasting the fruit, was seriously impaired. Since temperatures under 2.2 C did not appear to compromise fruit quality during a 2-week storage period, a storage temperature of 0 C was recommended. In an effort to ascertain the extent of internal breakdown upon storage at 0 and 4.4 C, these authors expanded their studies to cultivars not previously studied, and classified them according to their tolerance to breakdown, decay and loss of dessert quality (Harding and Haller, 1934). The greater severity of chilling injury at 5 C as opposed to 0 C, was also observed for the peach cultivars 'Rio Oso Gem', 'Loring', 'Blake' and 'Redskin', and for the nectarine cultivar 'Regal Grand', with similar results in that symptoms were much more intense at 5 C than at 0 C (Anderson, 1975). It has been a general observation that the optimum temperature for the development of chilling injury symptoms is often higher than that at which the injury itself takes place (Saltveit and Morris, 1990).

Several methods have been utilized in order to measure the extent of chilling injury in peaches. A practical method involves scoring the fruit based on the intensity of symptom development, such as mealiness or flesh browning (Ben-Arie et al., 1970; Anderson, 1979; Wade, 1981; Retamales et al., 1992). The flesh dryness associated with chilling injury was successfully measured using a succulometer (Ben-Arie and Lavee,

1971), which is a device that extracts juice by applying a constant pressure on the fruit pulp. Alternatively, other authors used a centrifugation procedure in order to separate the solids from the fluid fraction (Buescher and Furmanski, 1978; von Mollendorff et al., 1992a, 1992b).

The leakage of solutes due to chilling injury was measured as an increase in electrolyte leakage as well as in flesh electrical conductivity (Furmanski and Buescher, 1978). An increase in both parameters, however, was also observed in fruit that had been ripened with no prior chilling exposure. While both methods produced similar results, these authors noted that electrical conductivity was more sensitive than electrolyte leakage in the detection of chilling injury in peaches.

The rates of respiration and ethylene production have provided indirect evidence of chilling injury in peaches. It has been reported that the respiration rate of 'Peregrine' peaches decreased sharply at the onset of wooliness, which occurred when the fruit were transferred from 2 to 10 C. While the rate of ethylene production increased upon transfer of the fruit to 10 C, the magnitude of the increase was lower for fruits that would ultimately develop wooliness than for those that did not (von Mollendorff and de Villiers, 1988a).

The severity of chilling injury symptom development is dependent on the fruit's stage of ripeness. It has been observed that symptoms are not as severe when either peaches (O'Reilly, 1947; Ben-Arie and Lavee, 1971) or nectarines (von Mollendorff et al., 1992b; Retamales et al., 1992) are ripened before cold storage. Hardenburg et al. (1986) reported that the extent of chilling injury can be reduced by pre-ripening the fruit for 2 to 3 days at 21 to 24 C.

The use of controlled atmospheres (CA) to delay or prevent the development of chilling injury has yielded divergent results. In the cultivars 'Loring', 'Rio Oso Gem' and 'Blake' (Anderson and Penney, 1975), as well as in the cultivar 'J.H. Hale' (Wade, 1981), fruit in CA with high CO₂ (3-20%) and reduced O₂ (1-20%) did not show as quick an onset of chilling injury as air-stored fruit. Other authors, however, found no major improvement (O'Reilly, 1947), or even an aggravation in chilling injury as the concentration of atmospheric CO₂ was raised (Kader et al., 1982b).

The possibility of intermittent warming delaying or preventing chilling injury was also evaluated. Working with 'Elberta' peaches, Ben-Arie et al. (1970) reported the benefits of interrupting cold storage every 2 weeks with 2 days at 23-25 °C. A study of three peach cultivars ('Loring', 'Rio Oso Gem', and 'Blake') and one nectarine cultivar ('Regal Grand'), showed that higher fruit quality was attained when the fruit were temporarily transferred after either 3 or 6 weeks of storage at 0 °C to 18.3 °C for 2 days (Anderson and Penney, 1975).

A connection between the development of mealiness and the metabolism of pectic substances was reported by Ben-Arie and Lavee (1971). These authors related the loss of juiciness characteristic of chilled peaches to the formation of pectic gels, which are able to bind water. Those gels were thought to be long, low-methoxyl pectic chains, which resulted from pectin-methylesterase (PME) being greatly activated after a chilling treatment. Ben-Arie and Sonego (1980) and Artes et al. (1996) noted that this increase in the activity of PME observed during chilling injury development was accompanied by an inhibition in the activity of endo-PG.

Buescher and Furmaski (1978) concluded that it was after being transferred to ambient temperatures and not during the cold storage period when changes in the pectins occur in chill-injured fruit. Unlike Ben-Arie and Lavee (1971), Buescher and Furmaski (1978) related mealiness to the reduced activities of PME as well as PG, which in turn limited pectin solubilization.

The involvement of PME in the development of mealiness was not as conclusive in the experiments conducted by von Mollendorff and de Villiers (1988b). A lower activity of this enzyme was observed during the storage of some, but not all the fruit that developed chilling injury. A certain pattern was actually found for the activity of PG, which was depressed during the chilling treatment and surged abruptly when fruit were transferred to 10 C. The authors claimed that during the development of mealiness, reduced activity of PG resulted in the accumulation of pectins of high molecular mass, which acted as a water-binding gel.

The development of mealiness in nectarines was also associated with an impairment of pectin depolymerization (Dawson et al., 1992). These authors observed that, although de-esterification was able to proceed during storage at 2 C, upon removal from cold storage the pectins were not depolymerized and galactan side chains, which are removed from the pectin backbone during normal ripening, remained attached in mealy fruit.

In the study of pectin changes conducted by Cantor et al. (1992) on peaches at a threshold-mature stage (TM), after pre-ripening and storage at 0 C (PR), and after direct storage at 2 C (DS), a higher level of total extractable pectins on a fresh weight basis was detected in DS fruit, followed by PR, and finally by TM fruit. The concentration of

galacturonic acid and neutral sugars, and the degree of esterification did not differ significantly among pectic substances extracted from either DS, PR, or TM fruit. When comparing the profiles resulting from pectin fractionation, however, differences were observed among the three treatments. The authors indicated that, although the degree of esterification was not significantly different among DS, PR, or TM fruit, the spatial distribution of methyl esters was not necessarily the same among treatments, and the results might point to a small region of the pectin molecule that was highly deesterified in DS fruit.

A histological study of mealiness in peaches revealed that this disorder was characterized by a separation of mesocarp parenchyma cells leading to increased intercellular spaces and accumulation of pectic substances in the intercellular matrix (Luza et al., 1992). Minimal structural changes were apparent in the cellulosic component of the cell wall of mealy fruit. In fruit that developed leatheriness rather than mealiness, intercellular spaces also increased, but the mesocarp cell walls appeared to have thickened and adopted a very irregular contour (Luza et al., 1992).

A similar study on nectarines also related mealiness to an increase in the size of the intercellular spaces (von Mollendorff et al., 1992c). These authors noted that when fruit were removed from storage and allowed to ripen for a prolonged period of time to allow flesh firmness to reach 1 kg, mealiness was reversed. Histological observations of these fruit revealed comparatively smaller intercellular spaces.

CHAPTER 3

QUALITY PROFILE OF SELECTED MELTING- AND NONMELTING-FLESH PEACH GENOTYPES

Introduction

The peach is remarkably heterogeneous in its genetic base. This flexibility is manifested in the great phenotypic variability exhibited by the fruit, which has allowed cultivars to be classified based on the appearance and sensory characteristics of the fruit as round, flat or beaked; pubescent or smooth-skinned; freestone or clingstone; white-, yellow- or red-fleshed; sweet, sour or astringent; and melting- (MF) or nonmelting-fleshed (NMF) (Rom, 1988).

The main distinction between MF and NMF fruit is that the latter lack the rapid loss of firmness, known as “melting of the fruit,” characteristic of the final stages of ripening of MF fruit (Lester et al., 1996). The physiological difference between MF and NMF fruit lies in the reduced capability of the latter to degrade its cell walls (Postlmayr et al., 1956; Shewfelt, 1965). Water-soluble pectin, which has been shown to increase during normal ripening of MF peaches (Shewfelt et al., 1971), remains low during ripening of NMF peaches (Shewfelt, 1965). This behavior is explained by the fact that while MF peaches have both endo- and exo-polygalacturonase (PG), NMF types lack the endo-form of the enzyme (Pressey and Avants, 1978). The genetic disturbance behind the NMF trait can either occur at the translation level (Lester et al., 1994) or can be derived from a

complete deletion of the endo-PG gene, depending on the NMF genotype (Lester et al., 1996).

When MF peaches, which are usually grown for the fresh market, are left to ripen on the tree in order to achieve maximum quality, they show a propensity to mechanical damage and decay during shipping and handling that results in a reduced postharvest life (Robertson et al., 1992a). Unlike MF peaches, NMF cultivars are traditionally grown for canning purposes since the fruit maintain their integrity after undergoing the high-temperature retort treatment. These NMF cultivars, however, lack the red coloration, acidity, and aroma of commonly grown dessert-type MF fruit.

An important goal for current breeding programs is to develop NMF peach cultivars with fresh market sensory characteristics. The purpose is to develop fruit that are able to attain maximum flavor on the tree, yet maintain sufficient firmness to allow distribution under normal marketing channels (Sherman et al., 1990).

While sensory changes occurring during ripening of MF peaches have been thoroughly studied (Delwiche and Baumgardner, 1983; Chapman et al., 1991; Robertson et al., 1992b), NMF fruit intended for the fresh market have not received the same attention. The objective of the following study was to characterize MF and NMF cultivars based on their compositional and sensory attributes.

Materials and Methods

This study, which was part of the protocol followed for the determination of potential maturity indices, was conducted in 1994 and repeated, with modifications, in 1995. The plant material consisted of two genotypes of MF fruit: FL 90-20 and

'TropicBeauty' and two of NMF: Oro A' and FL 86-28C. All four genotypes were obtained from the Teaching Orchard, Horticultural Sciences Dept., University of Florida, Gainesville. Each NMF genotype was paired with a MF genotype of comparable maturity date. In Florida, FL 90-20 and 'Oro A' are extremely early-season genotypes. The fruit of FL 90-20 is yellow-fleshed, has 80% of skin red blush, and weighs approximately 80 g. The fruit of 'Oro A' is yellow-fleshed, has no red blush, and weighs approximately 70 g. 'TropicBeauty' and FL 86-28C are later- season genotypes. The fruit of 'TropicBeauty' is yellow-fleshed, has 80% of skin red blush, and weighs approximately 120 g. The fruit of FL 86-28C is yellow-fleshed, has 80% of skin red blush, and weighs approximately 115 g.

In 1994, fruit were harvested on three dates at intervals of seven days. The first harvest for 'Oro A' and its MF counterpart, FL 90-20, was conducted on April 23. The first harvest for FL 86-28C and its MF counterpart, 'TropicBeauty', was on May 10. On each date, harvesting was selective for those fruit whose ground color was representative of the average ground color for each genotype on that harvest date. Ground color parameters (L^* , a^* and b^*) for each genotype and harvest are shown in Chapter 4 (Table 4-3). The fruit collected at each harvest were considered to represent a maturity category. In the last harvest of the NMF selection FL 86-28C, a clear separation could be made between fruit with and without a well-developed abscission zone as judged by ease of fruit removal. Therefore, in this harvest, fruit were divided into two additional maturity categories based on this distinction.

After each harvest, a lot of fifteen fruit was set aside for sensory evaluation. Each lot was stored at 0 C for 14 days in order to simulate shipping/marketing conditions and subsequently allowed to ripen at 20 C. During ripening, ethylene production was

monitored, and when the ethylene peak was observed, the fruit were removed from storage and divided into two groups for sensory evaluation and chemical analysis.

For the measurement of ethylene production, a sample of three fruit from each harvest was weighed and placed in 1.75 L glass jars. The jars were sealed and after 1 hour, gas samples were removed through a rubber septum using 1 ml syringes. For gas analysis, injections of 0.5 ml were made into a Photovac 10A10 photoionization gas chromatograph (Photovac Inc., Thornhill, Ontario, Canada) equipped with a 0.003 x 1.0 m, 80/100 mesh activated alumina column and operated at ambient temperature with hydrocarbon-free air as the carrier gas.

The group for chemical analysis consisted of 15 fruit that were stored at -20 C until analyzed, when they were peeled, sliced, pitted and pureed in a Waring Blender for 1 minute. The slurry was centrifuged (20 minutes; 17,600xg; 6 C) and the fluid fraction was used for the determination of soluble solids, pH, and titratable acidity. Total soluble solids were measured on cheese-cloth-filtered samples using a Reichert-Jung, Abbe Mark II, digital refractometer (Cambridge Instruments Inc., Buffalo, New York, USA). Results were expressed in degree Brix.

For the measurement of the titratable acidity, 6 g of the fluid sample diluted in 50 ml of distilled water were placed on a Fisher stirrer and a 0.1N solution of NaOH was gradually dispensed by a Fisher burette/dispenser connected to a Fisher automatic titrimer model 381 (Fisher Scientific, Pittsburg, PA, USA). Titration continued to an end point of pH 8.2, when the total milliliters of NaOH used were recorded. Results were expressed as percentage of malic acid. The pH of the juice was measured using a Corning

pH meter model 140 (Corning Medical and Scientific Instruments, Halsted Essex, England).

In 1995, fruit were harvested on two dates at intervals of 7 days. The first harvest for 'Oro A' and FL 90-20 was on May 3 and for FL 86-28C and 'TropicBeauty' it was on May 22. Unlike 1994, in which harvesting was selective for fruit at the average stage of maturity, in 1995 harvesting was nonselective and all fruit on two trees per harvest were collected. Once in the laboratory, the fruit were separated into six classes based on a diameter scale that progressed in 0.16 cm-increments. Due to the fact that FL 90-20, FL 86-28C, and 'TropicBeauty' have fruit innately larger than those of 'Oro A', the initial class was 2.70 through 2.86 cm for the first three genotypes and 2.06 through 2.22 cm for 'Oro A'. The classification of the fruit, which was a modification of the procedure in 1994, was done in order to increase the number of fruit categories and expand the range of maturity levels.

After classification, lots of 12 fruit from each diameter class were reserved for sensory evaluation and were stored at 0 C for 1 week and subsequently allowed to ripen for 2 days at 20 C. This modification from the flexible ripening schedule of 1994, where ethylene production determined the timing of removal of the fruit, was done so that the sensory evaluation of each MF/NMF pair could be conducted side by side, rather than on different dates. The shortening of the storage time from 2 weeks in 1994 to 1 week in 1995 was done in order to accommodate fruit of more advanced maturity, that resulted from the classification scheme implemented in 1995.

Sensory evaluation procedures for 1994 and 1995 were identical. Fruit were peeled, sliced into approximately 1-cm wide wedges, which were mixed in a bowl and

presented in duplicate to a trained panel of 10 members, who recorded responses on a descriptive 15-point scale ballot (Fig. 3-1). Before the actual tests, all panelists received training in two sessions, during which they became familiar with the different varieties and stages of maturity and agreed on the sensory notes and their intensities. Two types of notes were assessed: textural aspects (hardness, rubberiness and juiciness) and flavor aspects (sweetness, sourness, bitterness, and green, peachy and overripe character).

Statistical design was intended to address the fact that not all genotypes had an equal number of maturity classes and that diameter classes identified with the same number did not necessarily coincide in their harvest date. Sensory evaluation results from 1994 were analyzed according to a randomized complete block design, with panelist as a random block effect, fixed genotype effects, and fixed harvest date effects nested within the genotype effects. Chemical analysis results were analyzed according to a two-stage nested design, with fixed genotype effects and fixed harvest effects nested within the genotype effects. Means were separated by pairwise t-tests. The experimentwise error was maintained within the boundaries of the fixed α by applying a Bonferroni correction that defined the magnitude of the pairwise comparisons error (Hsu, 1996).

In order to consolidate the results obtained from the sensory evaluation into a meaningful variable that allowed a comparison between MF and NMF fruit, principal component analysis was also conducted on the sensory data from 1994 and 1995. In 1994, results from all maturity classes were analyzed jointly, thus increasing the number of data points. In 1995, when fruit from the two harvests were separated into diameter classes, results were further analyzed based on harvest and diameter class.

Results and Discussion

The sensory ratings for the different MF and NMF genotypes in 1994 are shown in Table 3-1. Clear differences in the textural aspects of the fruit were detected between the two types of genotypes, with the NMF fruit being “harder,” less “juicy” and more “rubbery” than their MF counterparts. Differences between genotypes with the same type of flesh indicate that within MF or NMF types, some variability in the textural aspects can be anticipated. No grouping of the genotypes in any of the flavor notes could be established based on their flesh type (MF/NMF).

The first three principal components resulting from the principal component analysis of the 1994 sensory data explained 64% of the total variability, with the first principal component (PC1) explaining 28% of the variability, the second principal component (PC2) explaining 22% of the variability, and the third principal component (PC3) explaining 14% of the variability. (Table 3-2). All three principal components had Eigenvalues greater than 1.0, which is a criteria used for their selection (Pino et al., 1993).

The factor loadings shown in Table 3-2 give an indication of the importance of each sensory note within each of the principal components. It is apparent that all of the textural notes, “hardness,” “juiciness,” and “rubberiness,” had large impacts on the sensory assessment described by PC1. It is also evident that a contrast between negative and positive factor loadings can be established with PC1, with “sweetness,” “peach character,” and “overripe” being opposed to the other sensory notes. It could be argued that this contrast represents the difference between attributes associated with early stages of fruit

development (“hardness,” “sourness,” “green character,” etc.) and those associated with more advanced phases of ripening (“sweetness,” “peach character,” and “overripe”).

In order to obtain a graphic representation of the results as affected by the genotype, a two-dimensional scatter plot of PC1 vs. PC2 was constructed (Fig. 3-2). The data points are distributed in two bands along the PC1 axis, indicating that PC1 is effective at explaining total variation. The plot also reveals a clear distinction between the overall sensory assessments for MF and NMF fruit. Based on the importance of the textural notes in PC1, separate principal component analyses were conducted for the textural and flavor notes.

In the case of the textural principal components, PC1 explained 70% of the total variability and was the only principal component to show an Eigenvalue greater than 1.0. A plot of textural PC1 vs. textural PC2 also revealed a separation of MF and NMF fruit (Fig. 3-3).

In the case of the flavor principal components, the higher number of notes involved in their definition made it more difficult for a single principal component to explain a large proportion of the variation; however, the cumulative proportion of the variation explained by PC1 and PC2, both with Eigenvalues greater than 1, was 58%. A striking aspect of the plot of flavor PC1 vs. flavor PC2 was that the results for MF and NMF fruit appeared intermingled in the scatter plot (Fig. 3-4). These results suggest that, even when panelists were able to make an overall distinction between the two types of fruit (Fig. 3-2), it was the texture rather than the flavor attributes that accounted for this distinction. Likewise, the chemical analysis revealed that although differences in pH, titratable acidity, and

soluble solids were detected in the four genotypes analyzed (Table 3-3), no consistent grouping could be made based on the MF/NMF nature of the fruit.

In 1995, a high proportion (40%) of the total variation in the sensory data was explained by the first principal component (Table 3-4). An analysis of the factor loadings of PC1 reveals that the most pronounced contrast occurred between the “overripe” trait and the rest of the notes. This indicates an opposing behavior of the “overripe” note and the rest of the notes in the definition of PC1. In PC2, which explained an additional 14% of the total variation, a contrast can be established between “hardness,” “rubberiness,” “sourness,” and “green character” (notes associated with early stages of maturation) and the rest of the sensory notes.

When principal component analysis was applied separately to the textural and flavor notes, the results were in accordance with the trends reported for 1994. The first principal component for the textural analysis explained 60% of the variability and, with the second and the third principal components included, 100% of the variability was explained. As in 1994, the larger number of notes involved in the definition of the flavor principal components made it difficult for a single principal component to explain a large proportion of the variability. Flavor PC1 explained 40% of the variability and, with the inclusion of PC2 and PC3, 75% of the total variability was explained.

A graphic depiction of the principal component analysis conducted on the 1995 sensory data sorted by genotype is presented in Figures 3-5 (for all sensory notes), 3-6 (for textural notes only) and 3-7 (for flavor notes only). As in 1994, a distinction between MF and NMF can be established based on the overall sensory assessments as well as on the textural aspects of MF and NMF fruit, but not between their flavor aspects. Unlike

1994, however, a greater dispersion in the 1995 principal components can be observed (Figs. 3-5, 3-6, and 3-7). This dispersion could be due to the fact that in 1995 the sensory evaluation included twelve fruit categories (resulting from two harvests and six diameter classes), rather than three (resulting from three harvests) as in 1994.

The lack of separation in the flavor aspects of MF and NMF fruit substantiates the concept that the main difference between the two types of fruit lies in the textural rather than in the flavor aspects. This is a significant aspect since certain clingstone (NMF) genotypes have been reported to develop unpleasant off-flavors (Brecht et al., 1982; Sherman, personal communication).

The importance of textural attributes in the assessment of peach fruit sensory quality has been addressed by other authors. In a descriptive sensory study of maturation and ripening of 'Cresthaven' peaches, Lyon et al. (1993) noted that it was primarily texture and not aroma attributes that explained differences due to maturity or ripening of the fruit. From another angle, a survey of consumer perception of peach fruit characteristics that were relevant to its eating quality, ranked texture among the most important factors that determined the quality of the fruit (Bruhn, 1994).

When 1995 sensory results were sorted by harvest and diameter class rather than by genotype, the principal component analysis revealed a special clustering of the results. Figures 3-8 and 3-9 show the behavior of the principal components obtained by analyzing all the sensory notes. For the first harvest, a tendency for diameter classes to cluster along the PC1 axes in an ascending order (i.e. diameter class 1 closer to the origin and 6 farther away from it) can be observed (Fig. 3-8). For the second harvest, however, the clustering tendency was not as prevalent (i.e. diameter classes appear more intermingled), although

it was still apparent (Fig. 3-9). These results suggest that there may be a relationship between fruit diameter and the sensory aspects of the fruit, which may weaken as maturation continues on the tree. That is, in earlier harvests, the fruit of smaller diameter may still be in the growth phase of development, while, in later harvests, all of the fruit are more likely to have reached their full size.

Panelist Name..... Date..... Sample Code.....

Texture

Hardness

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Very Soft Very Hard

Juiciness

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Very Dry Very Juicy

Rubbery Character

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
No Rubbery Character High Rubbery Character

Flavor

Sweetness

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Not Sweet Very Sweet

Sourness

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Not Sour Very Sour

Bitterness

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Not Bitter Very Bitter

Green Character

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
No Green Character High Green Character

Peach Character

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
No Peach Character High Peach Character

Overripe Character

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
No Overripe Character High Overripe Character

Please, add comments if necessary.

Figure 3-1. Form used for the descriptive evaluation of ripe MF and NMF fruit

Table 3-1. Sensory ratings⁽¹⁾ for ripe MF and NMF fruit (1994)

Genotypes	Sensory notes							
	Hardness	Juiciness	Rubberiness	Sweetness	Sourness	Bitterness	Green char.	Peach char. Overripe
FL 90-20 (MF)	4.0 c ⁽²⁾	10.3 b	3.6 c	7.6 a	5.2 a	2.2 a	1.8 ab	9.2 a 2.3 b
Oro A (NMF)	9.0 b	7.1 c	8.3 a	7.5 a	4.7 b	2.8 a	2.4 ab	8.1 ab 1.2 b
TropicBeauty (MF)	1.3 d	11.8 a	0.4 d	6.5 ab	3.8 d	1.7 a	1.3 b	6.0 c 5.9 a
FL 86-28C (NMF)	10.1 a	6.3 c	5.7 b	5.8 b	4.1 c	2.3 a	2.9 a	7.0 bc 1.9 b

⁽¹⁾ Rating scale ranges from 1 (low intensity of the note) to 15 (high intensity of the note)⁽²⁾ Mean separation in columns by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

Table 3-2. Factor loadings for principal component analysis of sensory data (1994)

Note	PC1	PC2	PC3
Hardness	0.521	0.143	-0.223
Juiciness	0.482	0.113	-0.196
Rubberiness	0.410	0.017	-0.283
Sweetness	-0.046	0.507	0.186
Sourness	0.169	-0.076	0.738
Bitterness	0.133	0.433	0.319
Green Char.	0.251	0.358	0.216
Peach Char.	-0.204	0.518	-0.288
Overripe	-0.414	0.342	-0.132
% Cumulative variance	28	50	64

Table 3-3. Chemical attributes of ripe MF and NMF peaches (1994)

Genotype	pH	Soluble sol. (° Brix)	Titrateable ac. (% malic)	SS:TA
Melting flesh				
FL 90-20	3.93 ab ⁽¹⁾	10.2 b	1.50 bc	7.17 b
TropicBeauty	3.86 ab	10.5 b	2.06 a	6.00 c
Nonmelting flesh				
Oro A	3.97 a	12.0 a	1.68 b	7.59 b
FL 86-28C	3.84 b	11.9 a	1.39 c	9.26 a

⁽¹⁾Mean separation in columns by pairwise t-tests with Bonferroni correction at $\alpha=0.05$

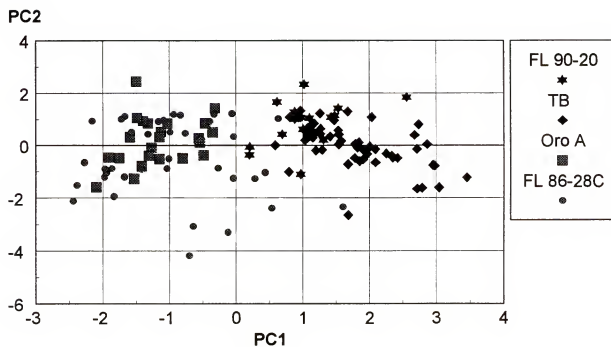


Figure 3-2. Plot of sensory PC1 vs. sensory PC2 (1994)

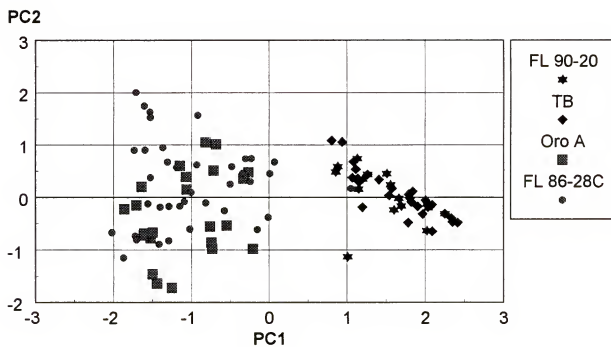


Fig. 3-3. Plot of textural PC1 vs. textural PC2 (1994)

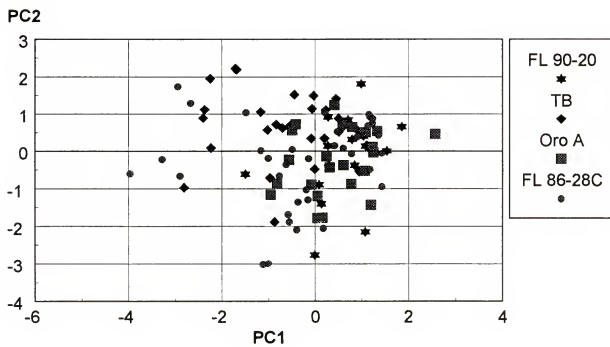


Figure 3-4. Plot of flavor PC1 vs. flavor PC2 (1994)

Table 3-4. Factor loadings for principal component analysis of sensory data (1995)

Note	PC1	PC2	PC3
Hardness	0.423	-0.237	0.141
Juiciness	0.461	0.026	0.072
Rubberiness	-0.021	-0.355	0.832
Sweetness	0.428	0.245	-0.050
Sourness	0.371	-0.151	-0.977
Bitterness	0.072	0.452	0.443
Green Char.	0.367	-0.141	1.032
Peach Char.	0.287	0.560	0.019
Overripe	-0.249	0.441	0.268
% Cumulative Variance	40	54	66

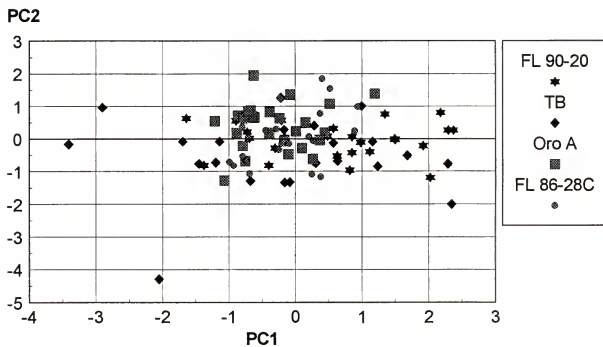


Figure 3-5. Plot of sensory PC1 vs. sensory PC2 (1995)

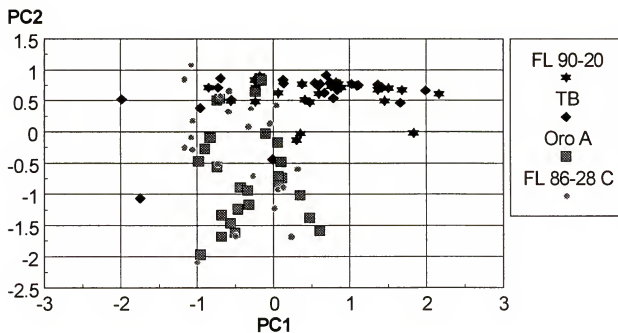


Figure 3-6. Plot of textural PC1 vs. textural PC2 (1995)

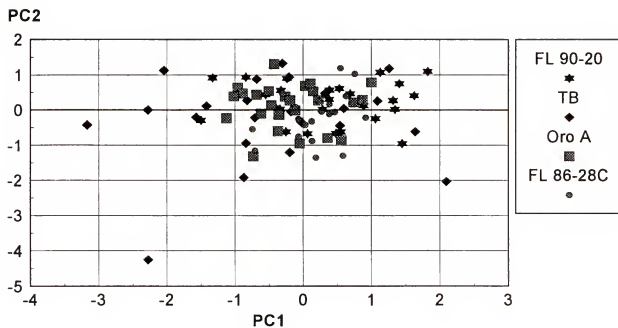


Figure 3-7. Plot of flavor PC1 vs. flavor PC2 (1995)

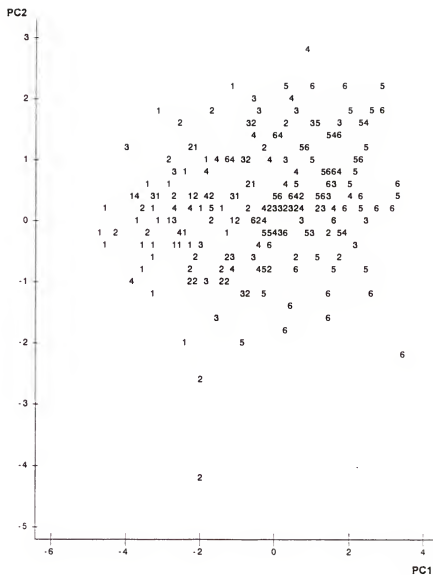


Figure 3-8. Plot of taste PC1 vs. taste PC2 sorted by diameter class for the first harvest of 1995 (numbers correspond to diameter class from smallest (1) to largest (6))

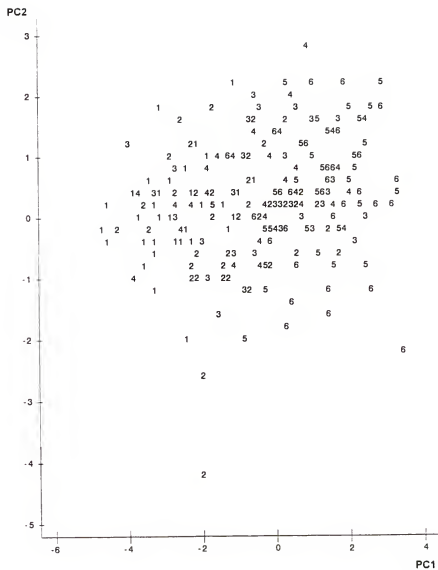


Figure 3-9. Plot of taste PC1 vs. taste PC2 sorted by diameter class for the second harvest of 1995(numbers correspond to diameter class from smallest (1) to largest (6))

CHAPTER 4

DEVELOPMENTAL ASPECTS AND POTENTIAL MATURITY INDICES OF SELECTED MELTING- AND NONMELTING-FLESH PEACH GENOTYPES

Introduction

The concept of horticultural maturity implies the utilization of a measurable character, changes in which can be used to indicate when a commodity should be harvested for a particular purpose. This character is known as a maturity or harvesting index (Reid, 1992). Maturity indices for various horticultural crops have relied on different features of the commodity, such as duration of development, size, density, starch or sugar content, color, firmness, etc., which provide an adequate estimate of maturity (Shewfelt, 1993).

The search for maturity indices for different peach varieties for the fresh market has been extensive. However, the methodology for their determination has differed considerably. A number of researchers focused on the correlations between different physicochemical attributes of the fruit or on the progression of these attributes with advancing maturity (Sims and Comin, 1963; Salunkhe et al., 1968; Delwiche and Baumgardner, 1985). Alternatively, other authors considered the relationship of various physicochemical aspects of the fruit at harvest with its edible quality. The determination of the fruit's edible quality, however, was not consistent among researchers. While Delwiche and Baumgardner (1983) and Meredith et al. (1989) measured acceptability by

means of sensory panels composed of 5-15 judges, Robertson et al. (1992b) used descriptive sensory panels, but did not assess the acceptability of the fruit.

Technological breakthroughs, such as delayed light emission (Forbus and Dull, 1990; Chapman et al., 1991) and microwave permittivity (Nelson et al., 1994), are emerging as potential means of detecting maturity in peaches. The main purpose of these approaches, however, is to assist in on-line processes, such as sorting and grading, and not in the harvesting scheme.

The decision of when to harvest peaches is a critical one. Overripe fruit are extremely susceptible to mechanical damage and decay. Immature fruit may not ripen to the standards required by consumers, and if stored under an inappropriate temperature regime, may develop undesirable attributes such as flesh “mealiness,” browning, etc., and other symptoms related to chilling injury.

It is therefore critical to determine when a peach fruit has reached horticultural maturity and can reach the consumer in satisfactory condition, after having undergone a specified storage and handling period. The objective of this study was to determine potential maturity indices for the NMF genotypes ‘Oro A’ and FL 86-28C.

Materials and Methods

The study, which initially concentrated on the NMF genotypes ‘Oro A’ and FL 86-28C, was started in 1994. In 1995, the MF genotypes FL 90-20 and ‘TropicBeauty’ were also included in order to compare the behavior of NMF with that of MF fruit. The source of the material was identical for 1994 and 1995 and was described in Chapter 3.

The methodological basis for the determination of a maturity index was to conduct a linear correlation between a series of physicochemical attributes measured at harvest and the final sensory assessments of the fruit, which resulted from a descriptive sensory evaluation. The attributes showing the best correlation coefficients are those with the best potential for becoming maturity indices.

Three issues borne in mind in the development of the protocol were: (1) since, in the case of peaches, paired observations (measurements at harvest and the corresponding sensory assessments for each fruit) are unrealizable due to the size of a fruit, data points in the correlation result from fruit of a specific grade rather than from individual fruit. In order to strengthen the correlation by increasing the number of data points, a grading scheme that resulted in a large number of fruit grades was implemented. The larger the number of fruit grades, the greater the chance of finding a significant correlation between measurements at harvest and sensory assessments, (2) the determination took into account a storage period that simulated the time that elapses from harvest to consumption in the commercial marketing chain, and (3) results from the descriptive sensory evaluation were consolidated into a single meaningful variable by means of principal component analysis. The first sensory principal component (PC1), which explains the highest proportion of the variability, was correlated with the physicochemical attributes measured at harvest.

The results from the 1994 harvest provided key information to conduct the determination of a maturity index in 1995. In 1994, fruit were harvested on three dates, as indicated in Chapter 3, at intervals of 7 days. In order to determine when to conduct the first harvest for each of the NMF genotypes, fruit diameter, as measured with a fruit gauge (Cranston, Inc., Oak Grove, Oregon, USA), was recorded over time for a sample of

twenty labeled fruit on each of three trees. The first harvest was to be conducted when the average fruit growth reached a plateau. On each harvesting date, collection was selective for those fruit whose ground color was representative of the average ground color for each genotype on its harvest date (Table 4-3). The fruit collected at each harvest were considered to represent a maturity category. In the last harvest of the NMF selection FL 86-28C, a clear separation could be made between fruit with and without a well-developed abscission zone as judged by ease of fruit removal. Therefore, in this harvest fruit were divided into two additional maturity categories based on this distinction.

Immediately after harvest, the fruit were brought into the laboratory and distributed in the following manner: fifteen fruit were set aside for the measurement of physicochemical attributes at harvest (diameter, fresh weight, peel ground color, flesh color and texture, pH, soluble solids, and titratable acidity), nine fruit were assigned to the measurement of ethylene production, and thirty fruit were stored at 0 C for 14 days and subsequently ripened at 20 C until the ethylene peak was observed. At this point, these fruit were removed from storage and divided in two lots of fifteen fruit each, one for the analysis of pH, soluble solids, and titratable acidity, and the other for sensory evaluation. In order to postpone the determination of pH, soluble solids, and titratable acidity, the fruit reserved for these measurements were stored at -20 C until analyzed. While no physicochemical attributes at harvest were measured for the MF genotypes in 1994, fruit from these genotypes were also harvested in order to characterize the production of ethylene and to conduct a chemical and sensory analysis of these cultivars after they were ripened.

In 1994, the correlation between attributes at harvest and sensory PC1 was conducted jointly for 'Oro A' and FL 86-28C, by using measurements at harvest and sensory assessments for both genotypes in combination. In this way, the variability existing for the nonmelting genotypes was represented more accurately. Since the goal was to have as many fruit categories as possible, based on the results from 1994, it was possible to define which attributes best correlated with the sensory PC1, and thus to determine which one of them had the best potential as a grading criterion for 1995.

While 1994 fruit categories were only based on their harvest dates, in 1995, fruit within each harvest were further divided into grades based on their diameter. The grading scale, which encompassed six diameter categories, is described in Chapter 3. Fruit within each grade were divided into three lots: nine fruit for the measurement of ethylene production and respiration rate, fifteen fruit for sensory evaluation after having been stored for 1 week at 0 C and ripened for 2 days at 20 C, and fifteen fruit for the measurement of physicochemical attributes at harvest. These physicochemical measurements at harvest were the same as in 1994, except for fresh weight, which was excluded, and the initial respiration rate, which was added to the list. In 1995, all measurements and evaluations were conducted alike for MF and NMF fruit.

Color (L^* , a^* and b^* values) was determined using a Minolta CR-200 reflectance colorimeter, under D_{65} illuminant conditions. Results were expressed as L^* value, hue angle, and chroma. Ground color was measured on the greenest (or least orange, in more advanced stages) portion of the peel. Flesh color in the cheeks (CH) was measured on a flat surface obtained by removing epicarp and mesocarp tissue from both sides of the fruit by slicing parallel to suture at the equator level to a depth of approximately 0.5 cm into

the flesh. Measurements were taken at both cheeks and results were averaged. Blossom-end (BE) flesh color was measured at approximately 0.5 cm into the flesh at the BE.

Flesh firmness was measured with an Instron (Model 1132), which applied compressive force from a 500 kg load cell. A convex-tip probe (Magness-Taylor type), 1.1 cm in diameter, was attached to the load cell moving at a speed of 10 cm/min. Firmness was evaluated on the same flat surfaces (CH and BE) where color was measured. Results are expressed as the force (N) required to reach the bioyield point or puncture force (Manness et al., 1992) of the tissue.

Soluble solids, pH, and titratable acidity were measured in the same way and using the same instruments described in Chapter 3.

For the measurement of ethylene production and respiration rate, three replicates of three fruit each were set up as described in Chapter 3. Ethylene was measured as described in Chapter 3 and results were expressed as $\mu\text{l C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$. The respiration rate was measured on the same fruit and gas samples were collected in the same manner as those for ethylene. For CO_2 gas analysis, 0.5 ml gas samples were injected into a Gow-Mac Series 580 gas chromatograph (Gow-Mac Instrument Co., Bridgewater, New Jersey, USA) equipped with a 0.003×1.98 m column packed with 80-100 mesh Columpak and a thermal conductivity detector. Column temperature was 40 C and injector and detector temperature was 90 C. Results, which are averages of three replicates, were expressed as $\text{ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$.

For the genotypes FL 90-20 and 'Oro A', a technique was devised to measure the respiration and ethylene production rates while the fruit were still attached to the tree. For this purpose, a set of 16 fruit on three trees were assigned to either the measurement of

ethylene or CO₂ and labeled accordingly. A rubber serum stopper (size 14, Fisher Scientific, Pittsburgh, Pennsylvania, USA) was attached to the fruit's epicarp in the cheek area using a noncorrosive silicon rubber adhesive (Dow Corning 3140 RTV Coating, Dow Corning, Midland, Michigan), which does not produce ethylene and is not injurious to the peel (Petracek, personal communication). Prior to attachment to the fruit, the stoppers were autoclaved for an hour so as to drive off all possible ethylene from them. Samples for ethylene and CO₂ determinations were removed through the septa using the appropriate syringes (described in Chapter 3) and analyzed using the instrumentation described above and in Chapter 3. Results are expressed as parts per million of ethylene and percent of carbon dioxide.

Data from the physicochemical determinations conducted in 1994 were analyzed according to a completely randomized design, with harvest date as a fixed effect. Results from the 1995 physicochemical determinations were analyzed according to a nested design, with fixed diameter class effects, nested within fixed genotype effects. Means were separated by pairwise t-tests with a Bonferroni correction (Hsu, 1996).

Results and Discussion

Developmental aspects of the fruit in 1994 are based on their evolution with sequential harvests and, in the case of fruit diameter, additional consideration is given to its variation for fruit on the tree (Fig. 4-1). It was observed that fruit on the tree kept growing past the first harvest. While the diameter of 'Oro A' fruit did not increase beyond the second harvest, in FL 86-28C the diameter continued to increase through the third harvest. A similar scenario was found for harvested fruit, where the difference in average

diameter between the first and the last harvest was 0.3 cm and 1 cm for 'Oro A' and FL 86-28C, respectively (Table 4-1).

The maximum difference in fresh weight between the sequential harvests was 22% and 52% of the minimum fresh weight for 'Oro A' and FL 86-28C, respectively (Table 4-1). These figures suggest that peach fruit do not have to reach full size to be able to complete normal development once detached from the plant. These findings are in disagreement with those that report that maturation and ripening of peaches occur once the fruit have stopped their growth (Connors, 1919; Delwiche and Baumgardner, 1983).

Significant increases in pH and decreases in titratable acidity were observed in both genotypes with maturation (Table 4-1). The soluble solids content, on the other hand, showed significant increases in FL 86-28C, but did not change during maturation in 'Oro A'. Significant increases in the ratio of soluble solids:titratable acidity were observed in both genotypes with maturity. In FL 86-28C, significant differences between fruit with and without development of an abscission zone were observed for all physicochemical aspects except the soluble solids content, with fruit with a developed abscission zone being larger and having higher pH, lower titratable acidity and higher soluble solids:titratable acidity ratio (Table 4-1).

The production of ethylene 24 h after the fruit were harvested tended to increase with maturity in both 'Oro A' and FL 86-28C (Table 4-2). Unlike most of the physicochemical attributes, the development of the abscission zone in fruit of FL 86-28C did not imply significant differences in the levels of ethylene production.

As for the color parameters, both the L^* value and the hue angle tended to decrease with maturation in all three regions of the fruit (Table 4-3). These trends indicate

that the fruit became darker and with a higher proportion of red components. In FL 86-28C, measurements of the hue angle at the BE were consistently lower than at the CH, indicating an earlier increase of the red and orange components in the BE region of the fruit. The apparent decrease in chroma (decrease in color purity) observed in the peel ground color and in the CH flesh color of 'Oro A', was not observed in FL 86-28C.

A significant decrease in firmness with maturation was observed in the CH region of the fruit for both genotypes (Table 4-4). In FL 86-28C, the CH texture of fruit with a developed abscission zone was remarkably less firm than that of fruit without development of an abscission zone. Measurements of texture at the BE for FL 86-28C also showed a significant decline between the first and second harvest. For a given stage of maturity, readings in this region of the fruit were consistently higher than those in the CH. Firmness at the BE of fruit with a developed abscission zone at harvest 3 was significantly lower than fruit at harvest 2, but was not significantly lower than fruit without development of an abscission zone at harvest 3.

The linear correlation between the fruit attributes at harvest and sensory PC1 revealed which of the fruit attributes best correlated with the final assessment of edible quality for 1994. Following are the five attributes with the highest correlation coefficients, all of which were highly significant ($P < 0.01$): BE hue (-0.96), BE texture (-0.95), diameter (0.90), titratable acidity (-0.83), and soluble solids:titratable acidity ratio (0.80).

The identification of the five attributes shown above was critical in the definition of an additional parameter that allowed for the separation of the fruit into multiple categories

for the 1995 harvests. From all the attributes listed, fruit diameter was selected as it was nondestructive and easy to implement as a grading criterion.

Developmental aspects of the fruit in 1995 are a reflection of the changes associated with harvest date as well as fruit diameter. As for the chemical attributes of all four genotypes, a trend of significant increases in pH and the ratio of soluble solids:titratable acidity, and significant decreases in titratable acidity were observed between fruit of the smallest diameter in harvest one (H1-D1) and those of the largest diameter in harvest 2 (H2-D6) (Tables 4-5 and 4-6). The soluble solids content showed significant increases between these two fruit categories in all the genotypes, except in the MF selection FL 90-20.

Although ethylene production measured 24 h after harvest tended to increase between H1-D1 and H2-D6 in all four genotypes, an impressive difference in the ethylene production rates was detected between MF and NMF fruit (Table 4-7). While 'Oro A' and FL 86-28C, both NMF cultivars, showed maximum rates of $48.94 \mu\text{l kg}^{-1} \text{h}^{-1}$ and $49.69 \mu\text{l kg}^{-1} \text{h}^{-1}$, respectively, FL 90-20 and 'TropicBeauty', had maximum rates of only $4.87 \mu\text{l kg}^{-1} \text{h}^{-1}$ and $9.87 \mu\text{l kg}^{-1} \text{h}^{-1}$, respectively.

The respiration rate measured 24 h after harvest was not as impressively affected by either the harvest date or the fruit's diameter. Neither did those rates appear to differ greatly between MF and NMF fruit. (Table 4-7).

The most prevalent trend in the color parameters was a decrease in the hue angle with later harvest and increasing diameter in all the regions measured and all four genotypes. This trend reflects the increase in red and orange pigmentation (anthocyanins and carotenoids) occurring during maturation. As in 1994, hue angle measurements of the

CH flesh were consistently higher than those at the BE, thus indicating a higher proportion of red and orange components in the BE region of the fruit (Table 4-8 and 4-9).

Significant decreases in both CH and BE texture were detected in all four genotypes with increasing diameter and later harvests. As expected, this drop in firmness was much more impressive in MF genotypes than in their NMF counterparts. As pointed out in the discussion of the 1994 results, for a given harvest-diameter class, texture measurements at the BE were generally higher than those at the CH region of the fruit (Table 4-10).

In 1995, individual linear correlations were conducted between each genotype's fruit attributes at harvest and their respective sensory PC1 values. The attributes with the highest correlation coefficients and their statistical significance are shown in Table 4-11. It is apparent that each genotype has different attributes that best correlate with their respective sensory PC1. However, two attributes: BE texture and CH texture, were highly correlated with sensory PC1s in all four genotypes under study. This demonstrates the importance of texture as a potential maturity index, even in NMF genotypes, where decreases in flesh firmness with maturation are not as impressive as in MF types.

It should be noted that instrumental texture measurements in the field are destructive and lack the accuracy of laboratory determinations. The ideal scenario would involve training pickers to manually detect when a fruit has reached a firmness level that has experimentally been proven to be a good maturity threshold.

Based on the magnitude of the factor loadings for each genotype's PC1 (Table 4-12), it can be inferred that the attributes shown in Table 4-11 do not only provide an

indication of the fruit's final quality assessment as determined by PC1, but are also a fair reflection of most of the individual sensory notes.

The pattern of ethylene production over time for fruit harvested in 1994 reflected the different developmental stages at which the fruit were harvested. For the genotypes 'Oro A' and FL 90-20 (Fig 4-2), fruit from the first harvest were either at the climacteric rise ('Oro A') or at the preclimacteric phase (FL 90-20) of ethylene production. Fruit from the second harvest were at or near the climacteric peak ('Oro A') or the climacteric rise (FL 90-20). Fruit from the third harvest were either entering their postclimacteric phase ('Oro A') or reaching their climacteric peak (FL 90-20) shortly after harvest. According to these observations, fruit of 'Oro A' from all three harvests were at a more advanced stage of physiological development than those of FL 90-20.

The pattern of ethylene production was also a reflection of the developmental stage of the fruit at harvest in the genotypes FL 86-28C and 'TropicBeauty' (Fig. 4-3). In this case, however, both genotypes appeared to be more synchronized in their development, with fruit from the first harvest having been harvested at the preclimacteric phase, fruit from the second harvest at their climacteric rise, and fruit from the third harvest close to the climacteric peak. The development of an abscission zone did not imply apparent differences in the fruit's ethylene production pattern, with fruit with and without development of an abscission zone both reaching their climacteric soon after harvest and their postclimacteric phase shortly after that.

An obvious difference was observed in the absolute levels of ethylene production between the MF and the NMF genotypes. At the climacteric peak, the level of ethylene production in NMF genotypes ($50 \mu\text{l kg}^{-1} \text{h}^{-1}$) was distinctively higher than in MF

genotypes ($25\text{--}30\ \mu\text{l kg}^{-1}\text{ h}^{-1}$). This trend is in contrast with that reported by El-Agamy et al. (1981) and Biggs et al. (1982), who suggested that the biological basis behind the slow-softening trait (NMF) in peaches was a reduced capability for ethylene production.

As in 1994, the pattern of ethylene production for fruit harvested in 1995 was a good indicator of the developmental stage of the fruit at harvest (Fig 4-4 through 4-7). In general terms, fruit from the second harvest, whether MF or NMF, were at a more advanced phase in their ethylene production pattern than those from the first harvest. It would also appear that when the differences in initial ethylene production among diameter grades were considerable, those differences were maintained later in other phases of the ethylene production pattern. In other words, the level of ethylene production at the climacteric peak was not the same for fruit of different harvest dates or diameters. Exceptionally, fruit of the smallest diameter class had low initial rates of ethylene production, which soon rose to levels higher than those observed for larger diameter fruit. Peach seeds being an important source of endogenous ethylene (Jerie and Chalmers, 1976; Miller et al., 1988), it could be argued that fruit of the smallest diameter have not completed the process of endocarp lignification and, at this stage, the endocarp does not represent the barrier that once lignified, it imposes to gas diffusion (Miller et al., 1988).

The difference in the absolute levels of ethylene production between the MF and the NMF genotypes detected in 1994 was also observed in 1995. While the MF genotypes reached peak levels of $25\text{--}45\ \mu\text{l kg}^{-1}\text{ h}^{-1}$, NMF genotypes attained maximum levels of $80\text{--}200\ \mu\text{l kg}^{-1}\text{ h}^{-1}$.

A similar relationship between the respiratory drift and the fruit's developmental stage can be established (Fig. 4-8 through 4-11). In general, fruit from the second harvest

appeared to be in a more advanced phase of their respiratory drift than those from the first harvest. The maximum respiration rate observed for NMF genotypes ranged between 40-100 ml CO₂ kg⁻¹ h⁻¹ and that for MF genotypes between 40-50 ml CO₂ kg⁻¹ h⁻¹.

The measurement of the ethylene production for fruit on the tree followed a climacteric pattern for both 'Oro A' and FL 90-20 (Fig. 4-12). However, the same distinction between MF and NMF fruit noted in measurements of ethylene production off the plant can be made regarding the measurements of ethylene levels in fruit on the plant. The level of ethylene production at the peak on the tree was 50 ppm for the NMF genotype 'Oro A' and 16 ppm for MF genotype FL 90-20.

As for the CO₂ production on the plant, both genotypes exhibited climacteric behavior (Fig. 4-13). Unlike the production of ethylene, which showed a clear climacteric trend, the production of CO₂ of individual fruit tended to oscillate more. The production of CO₂ was comparable for the MF and the NMF genotype.

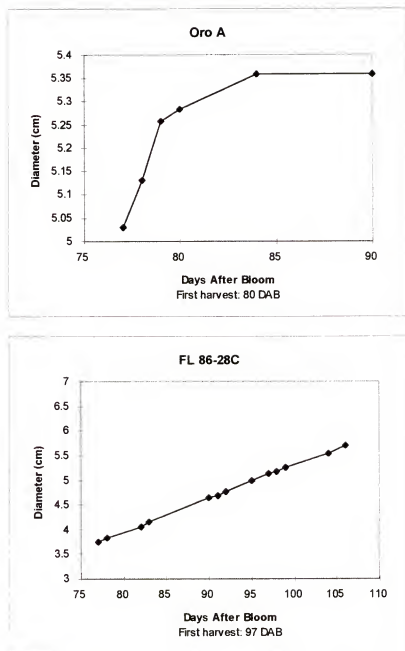


Figure 4-1. Growth curve for NMF fruit on the tree

Table 4-1. Physicochemical attributes of the fruit at harvest (1994)

Genotype	Harvest	Diameter (cm)	Fresh wt. (g)	pH	Soluble sol. (° Brix)	Titration acidity (% malic acid)	SS:TA
Oro A (NMF)	1	4.8 c ⁽³⁾	59.2 b	3.59 b	10.2 a	2.11 a	4.85 c
	2	5.3 a	72.5 a	3.77 a	10.1 a	1.68 b	6.00 b
	3	5.1 b	62.5 b	3.81 a	10.7 a	1.53 b	7.08 a
FL 86-28C (NMF)	1	4.8 d	67.8 d	3.51 d	10.2 bc	1.98 a	5.17 c
	2	5.3 c	83.4 c	3.63 c	10.4 abc	1.50 b	7.01 b
	3 w/o abs. ⁽¹⁾	5.5 b	93.1 b	3.71 b	11.2 ab	1.41 b	8.01 b
	3 w/ abs. ⁽²⁾	5.8 a	103.4 a	3.90 a	11.1 a	0.97 c	11.41 a

⁽¹⁾ Fruit without abscission zone development ⁽²⁾ Fruit with developed abscission zone

⁽³⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

Table 4-2. Rate of ethylene production measured 24 h. after harvest (1994)

Genotype	Harvest	Ethylene production ($\mu\text{l C}_2\text{H}_4/\text{kg.h}$)
Oro A (NMF)	1	27.08 b ⁽³⁾
	2	37.18 b
	3	61.08 a
FL 86-28C (NMF)	1	2.20 c
	2	20.45 b
	3 w/o abs. ⁽¹⁾	57.25 a
	3 w/ abs. ⁽²⁾	49.08 a

⁽¹⁾ Fruit without abscission zone development ⁽²⁾ Fruit with developed abscission zone

⁽³⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

Table 4-3. Ground, cheek flesh, and blossom-end flesh color of the fruit at harvest (1994)

Genotype	Harvest	Ground color			Cheek flesh color			Blossom-end flesh color		
		L*	Hue	Chroma	L*	Hue	Chroma	L*	Hue	Chroma
Oro A (NMF)	1	102.8 a ⁽³⁾	67.0 b	73.2 a	102.8 a	94.4 a	81.7 a	n.a. ⁽⁴⁾	n.a.	n.a.
	2	66.0 b	86.3 a	60.0 b	66.0 b	88.3 a	60.0 b	n.a.	n.a.	n.a.
	3	67.7 b	82.4 a	56.5 b	67.7 b	83.5 a	50.5 c	n.a.	n.a.	n.a.
FL 86-28C (NMF)	1	71.4 a	97.7 a	54.4 a	72.8 a	91.9 a	60.2 b	68.9 b	89.7 a	50.4 c
	2	64.0 b	71.0 b	53.3 a	72.7 a	87.3 b	64.0 a	71.5 a	81.6 b	67.0 a
	3 w/o abs. ⁽¹⁾	n.a.	n.a.	n.a.	70.9 b	84.5 b	62.4 ab	70.9 ab	80.0 bc	64.3 ab
	3 w/ abs. ⁽²⁾	n.a.	n.a.	n.a.	64.4 b	77.3 c	60.7 ab	68.7 b	75.1 c	61.5 b

⁽¹⁾ Fruit without abscission zone development ⁽²⁾ Fruit with developed abscission zone⁽³⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$ ⁽⁴⁾ Not available: Ground color not determined past 2nd harvest in FL 86-28C since fruit were fully "blushed". No blossom-end measurements were included in experimental design for 'Oro A'

Table 4-4. Cheek and blossom-end firmness of the fruit at harvest (1994)

Genotype	Harvest	Cheek firmness (N)		Blossom-end firmness(N)	
		54 a ⁽³⁾	35 b	n.a. ⁽⁴⁾	n.a.
Oro A (NMF)	1	54 a ⁽³⁾	35 b	n.a.	n.a.
	2	35 b	30 b	n.a.	n.a.
	3	30 b			
FL 86-28C (NMF)	1	96 a	62 b	113 a	
	2	62 b	64 b	74 b	
	3 w/o abs. ⁽¹⁾	64 b	36 c	72 bc	
	3 w/ abs. ⁽²⁾	36 c		56 cd	

⁽¹⁾ Fruit without abscission zone development ⁽²⁾ Fruit with developed abscission zone⁽³⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$ ⁽⁴⁾ Not available: No blossom-end measurements were included in experimental design for 'Oro A'

Table 4-5. Physicochemical attributes of 'Oro A' and FL 90-20 at harvest (1995)

Genotype	Harvest	Diam. class	pH	Soluble sol. (° Brix)	Titration acidity (% malic)	SS/TA
Oro A (NMF)	1	1	3.79 cd ⁽¹⁾	9.55 b	2.23 a	4.53 c
		2	3.81 bcd	10.07 b	2.03 ab	4.70 bc
		3	3.88 abcd	10.57 b	1.82 abc	6.11 bc
		4	4.04 a	10.32 b	1.68 abc	6.60 abc
		5	3.91 abcd	16.07 a	1.40 bc	11.67 a
		6	3.94 abcd	12.52 ab	1.26 c	10.11 abc
	2	1	3.76 d	10.12 b	1.68 abc	6.10 bc
		2	3.99 abcd	11.32 ab	1.30 c	8.82 abc
		3	3.92 abcd	10.37 b	1.42 bc	7.88 abc
		4	4.04 ab	10.22 b	1.31 c	7.92 abc
		5	3.93 abcd	12.72 ab	1.29 c	10.11 ab
		6	4.00 abc	11.47 ab	1.34 bc	8.61 abc
FL 90-20 (MF)	1	1	3.64 b	9.77 a	1.43 abc	6.74 b
		2	3.64 b	7.27 a	1.61 ba	4.45 b
		3	3.61 b	10.1 a	1.97 a	5.24 b
		4	3.71 b	9.80 a	1.70 ab	5.77 b
		5	3.74 b	10.55 a	1.65 ab	6.44 b
		6	3.63 b	10.20 a	1.59 ab	6.41 b
	2	1	n.a. ⁽²⁾	n.a.	n.a.	n.a.
		2	4.02 ab	10.77 a	1.25 bcd	9.25 ab
		3	3.93 ab	9.37 a	0.90 cde	10.58 ab
		4	4.28 a	10.07 a	0.68 c	15.11 a
		5	4.21 a	10.67 a	0.75 ed	14.77 a
		6	n.a.	n.a.	n.a.	n.a.

⁽¹⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

⁽²⁾ Not available: Insufficient quantity of fruit of that particular class was available for analysis

Table 4-6. Physicochemical attributes of FL 86-28C and 'TropicBeauty' at harvest (1995)

Genotype	Harvest	Diam. class	pH	Soluble sol. (° Brix)	Titrate acidity (% malic)	SS/TA
FL 86-28C (NMF)	1	1	3.60 c ⁽¹⁾	9.2 ab	1.72 a	5.36 c
		2	3.69 c	7.9 b	1.29 ab	6.46 c
		3	3.87 abc	9.4 ab	1.12 b	8.68 bc
		4	3.90 abc	10.2 ab	1.07 b	9.83 abc
		5	3.77 bc	9.8 ab	1.27 ab	8.02 bc
		6	4.13 ab	10.5 ab	0.79 b	13.30 ab
	2	1	3.86 abc	10.8 ab	0.95 b	11.81 abc
		2	3.84 abc	11.1 ab	1.18 ab	10.16 abc
		3	3.89 abc	11.4 ab	1.02 b	11.28 abc
		4	3.89 abc	11.6 a	1.03 b	11.42 abc
		5	3.90 abc	11.2 ab	1.17 ab	9.72 abc
		6	4.21 a	11.9 a	0.77 b	16.03 a
TropicBeauty (MF)	1	1	n.a. ⁽²⁾	n.a.	n.a.	n.a.
		2	3.61 bc	8.42 b	2.36 a	3.58 c
		3	3.63 bc	11.30 ab	2.19 ab	5.16 bc
		4	3.60 c	11.52 ab	2.17 ab	5.33 bc
		5	3.58 c	10.95 ab	2.00 abc	5.45 bc
		6	3.80 a	12.40 a	1.44 d	8.67 a
	2	1	n.a.	n.a.	n.a.	n.a.
		2	3.77 a	8.52 b	1.77 bcd	4.89 bc
		3	3.72 bc	12.30 a	1.71 dc	7.24 ab
		4	3.75 ab	12.20 a	1.77 bcd	6.88 ab
		5	n.a.	n.a.	n.a.	n.a.
		6	3.86 a	12.95 a	1.50 d	8.86 a

⁽¹⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

⁽²⁾ Not available: Insufficient quantity of fruit of that particular class was available for analysis

Table 4-7. Rate of respiration and ethylene production measured 24 h after harvest (1995)

Harvest	Grade	Genotypes					
		Oro A (NMF)		FL 90-20 (NMF)		FL 86-28C (NMF)	
		Ethylene production ($\mu\text{l C}_2\text{H}_4/\text{kg.h}$)	Respiration rate ($\text{ml CO}_2/\text{kg.h}$)	Ethylene production ($\mu\text{l C}_2\text{H}_4/\text{kg.h}$)	Respiration rate ($\text{ml CO}_2/\text{kg.h}$)	Ethylene production ($\mu\text{l C}_2\text{H}_4/\text{kg.h}$)	Respiration rate ($\text{ml CO}_2/\text{kg.h}$)
1	1	4.10 d ⁽¹⁾	35.15 a	1.07 d	32.71 a	20.91 b	43.45 b
	2	44.93 abc	49.78 a	2.72 abcd	35.25 a	35.17 ab	45.55 b
	3	55.62 a	51.75 a	1.96 bcd	36.82 a	36.87 ab	49.11 b
	4	48.94 ab	41.55 a	4.15 abcd	31.18 a	41.47 ab	47.15 b
	5	40.58 abc	43.08 a	2.26 abcd	34.00 a	33.62 ab	36.21 b
	6	38.67 abc	55.27 a	3.18 abcd	33.67 a	49.69 a	36.65 b
2	1	18.62 cd	14.27 b	1.56 cd	34.93 a	16.49 b	22.10 b
	2	25.61 bcd	55.07 a	3.09 abcd	42.12 a	43.25 a	66.55 a
	3	54.48 a	47.57 a	2.18 abcd	32.23 a	34.66 ab	28.86 b
	4	44.36 abc	48.57 a	4.49 ab	26.62 a	25.15 b	32.53 b
	5	36.95 abc	55.68 a	4.17 abc	38.10 a	35.28 ab	22.32 b
	6	53.87 a	49.54 a	4.87 a	29.72 a	n.a.	n.a.
TropicBeauty (MF)						Ethylene production ($\mu\text{l C}_2\text{H}_4/\text{kg.h}$)	Respiration rate ($\text{ml CO}_2/\text{kg.h}$)
						n.a.	n.a.
						1.80 c	30.46 ab
						1.65 c	24.26 b
						4.86 b	30.81 ab
						4.31 b	31.16 ab
TropicBeauty (MF)						9.87 a	36.26 a
						n.a.	n.a.
						n.a.	n.a.
						n.a.	n.a.
						n.a.	n.a.
						n.a.	n.a.

⁽¹⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$ ⁽²⁾ Not available. Insufficient quantity of fruit of that particular class was available for analysis

Table 4-8. Ground, cheek flesh, and blossom-end flesh color of 'Oro A' and FL 90-20 at harvest (1995)

Genotype	Harvest	Grade	Ground color			Cheek flesh color			Blossom-end flesh color		
			L*	Hue	Chroma	L*	Hue	Chroma	L*	Hue	Chroma
Oro A (NMF)	1	1	66.1 bc ⁽¹⁾	97.5 a	51.0 d	69.8 ab	92.2 a	57.1 a	70.1 a	91.1 a	63.8 a
		2	65.5 c	96.0 a	51.1 d	70.6 ab	90.3 ab	56.2 abc	70.5 a	87.4 ab	65.7 a
		3	65.8 abc	89.9 b	52.7 cd	69.4 b	87.1 ab	54.3 abcd	70.4 a	85.0 ab	64.6 a
		4	66.3 abc	89.4 b	53.8 cd	71.1 ab	87.1 ab	52.1 bcde	70.4 a	84.3 ab	64.9 a
		5	67.0 abc	86.0 bc	54.4 bc	70.3 ab	85.8 ab	53.5 abcde	69.9 a	83.4 ab	61.0 a
		6	67.6 abc	83.7 cd	54.6 abc	69.8 ab	85.4 ab	50.4 de	71.8 a	84.7 ab	53.9 b
	2	1	66.1 bc	89.4 b	54.0 cd	69.1 b	86.4 ab	56.7 ab	70.8 a	84.6 ab	64.6 a
		2	67.9 ab	82.0 cd	57.8 a	70.1 ab	83.9 bc	50.7 de	70.6 a	80.4 bc	64.9 a
		3	67.6 bc	85.5 bcd	55.8 abc	70.9 ab	86.2 ab	52.4 abcde	70.8 a	81.4 bc	63.3 a
		4	68.6 a	82.7 cd	57.7 a	71.7 a	84.8 ab	49.6 de	71.1 a	82.0 bc	63.3 a
		5	67.2 abc	81.6 cd	57.2 ab	70.2 ab	76.0 c	51.6 cde	69.0 a	74.4 c	60.4 ab
		6	67.6 abc	80.9 d	57.6 a	70.7 ab	84.4 ab	49.0 e	70.4 a	81.9 bc	59.3 ab
FL 90-20 (MF)	1	1	67.3 a	76.7 a	49.2 a	69.2 b	81.1 b	48.4 c	73.4 a	85.7 a	55.4 a
		2	61.8 abc	65.5 ab	44.6 b	75.4 a	91.7 a	53.9 abc	71.1 ab	76.4 ab	61.6 a
		3	62.1 abc	64.4 abc	44.6 b	76.6 a	91.1 a	55.5 ab	69.0 ab	74.5 a	56.2 a
		4	64.0 ab	68.2 ab	46.3 ab	73.8 ab	88.5 a	57.0 a	72.3 ab	79.9 ab	56.8 a
		5	62.4 abc	66.8 ab	45.8 ab	75.3 a	89.2 a	58.0 a	68.5 ab	76.2 ab	57.4 a
		6	58.0 bc	56.3 bc	47.6 ab	74.3 ab	84.9 ab	55.2 ab	67.7 ab	74.4 b	56.3 a
	2	1	59.7 abc	65.0 abc	45.9 ab	73.7 ab	87.1 ab	57.8 a	72.5 ab	81.0 ab	60.5 a
		2	57.5 bc	57.5 bc	44.4 b	74.0 ab	87.7 ab	56.6 a	72.5 ab	81.2 ab	58.1 a
		3	59.1 abc	57.7 bc	46.0 ab	73.2 ab	85.5 ab	56.0 a	73.7 a	86.2 ab	56.8 a
		4	58.6 abc	61.9 abc	46.1 ab	72.4 ab	87.1 ab	54.3 ab	72.9 ab	83.8 ab	62.2 a
		5	58.6 abc	59.1 abc	48.1 ab	72.9 ab	86.8 ab	55.1 ab	73.1 ab	83.7 ab	59.6 a
		6	53.6 c	47.2 c	47.3 ab	71.9 ab	85.2 ab	50.1 bc	72.6 b	80.1 ab	55.3 a

⁽¹⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$

Table 4-9. Ground, cheek flesh, and blossom-end flesh color of FL 86-28C and 'TropicBeauty' at harvest (1995)

Genotype	Harvest	Grade	Ground color			Cheek flesh color			Blossom-end flesh color		
			L*	Hue	Chroma	L*	Hue	Chroma	L*	Hue	Chroma
FL 86-28C (NMF)	1	1	68.8 a ⁽¹⁾	86.6 a	50.6 b	74.2 a	93.3 a	59.1 abc	74.0 a	88.8 a	65.1 a
		2	65.0 ab	70.9 b	53.9 ab	73.4 ab	86.4 b	60.3 abc	71.5 a	80.1 b	66.2 a
		3	63.3 abc	67.3 bc	54.8 ab	71.9 abc	83.8 cb	59.4 abc	71.0 a	77.6 bc	63.2 a
		4	61.8 bc	61.8 bc	57.3 a	72.5 abc	82.4 cb	59.5 abc	71.6 a	76.9 bc	64.4 a
		5	61.4 bc	61.8 bc	54.2 ab	72.0 abc	81.8 bc	59.9 abc	71.2 a	77.0 bc	64.0 a
		6	64.4 ab	62.7 bc	57.5 a	71.6 abc	79.4 cd	55.8 c	69.8 a	72.8 cd	61.0 a
	2	1	62.7 abc	62.6 bc	55.9 a	70.8 bc	83.0 bc	63.5 a	69.4 a	76.6 bcd	63.6 a
		2	61.8 bc	64.3 bc	54.4 ab	70.7 bc	83.3 bc	61.7 ab	69.7 a	77.8 bc	64.8 a
		3	61.8 bc	61.3 bc	56.6 a	71.2 abc	81.9 bc	62.9 a	69.3 a	76.0 bcd	65.7 a
		4	62.3 bc	63.3 bc	56.9 a	70.7 bc	82.3 bc	57.4 bc	68.9 a	77.1 bc	63.4 a
		5	59.4 bc	57.5 c	55.1 ab	69.8 cd	80.9 bcd	60.8 ab	68.4 a	76.3 bc	66.5 a
		6	57.9 c	57.3 c	56.9 a	67.1 d	76.0 d	57.1 bc	90.4 a	70.1 d	64.4 a
TropicBeauty (MF)	1	1	n.a. ⁽²⁾	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		2	68.3 a	83.5 a	48.8 a	78.0 a	90.2 a	55.7 ab	74.2 a	85.9 a	62.8 a
		3	65.8 a	72.5 ab	49.8 a	75.8 ab	85.6 ab	54.2 ab	72.4 ab	81.3 ab	62.7 a
		4	64.2 ab	66.7 bc	49.4 a	75.8 ab	85.0 ab	56.0 ab	73.0 a	81.5 ab	63.9 a
		5	64.7 ab	67.5 bc	50.1 a	75.6 ab	84.3 abcd	54.6 ab	69.6 abc	76.5 abc	61.4 a
		6	61.8 abc	64.6 bc	50.7 a	62.7 d	73.5 e	51.2 b	61.5 e	66.6 c	58.6 a
	2	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		2	63.1 abc	66.5 bc	48.1 a	70.1 bc	79.3 bcd	57.6 a	66.6 bcd	73.4 bc	61.6 a
		3	61.6 abc	62.0 bc	50.4 a	68.4 cd	78.1 cde	57.8 a	68.1 abcd	76.6 abc	64.4 a
		4	58.2 bc	56.5 c	49.0 a	67.4 cd	77.2 de	56.8 ab	62.2 de	68.7 c	60.6 a
		5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		6	57.7 c	57.0 c	49.7 a	64.9 cd	78.2 cde	52.5 ab	66.0 cde	75.9 abc	59.2 a

⁽¹⁾ Means within columns for each genotype were separated by pairwise t-tests with Bonferroni correction at experimentwise $\alpha=0.05$ ⁽²⁾ Not available. Insufficient quantity of fruit of that particular class was available for analysis

Table 4-12. Factor loadings for first sensory principal components (1995)

Note	Oro A (NMF)	FL 90-20 (MF)	FL 86-28C (NMF)	Tropic Beauty (MF)
Hardness	0.391	0.418	-0.396	0.412
Juiciness	0.448	0.448	0.466	0.447
Rubberiness	-0.278	0.085	-0.243	0.328
Sweetness	0.422	0.417	0.400	0.395
Sourness	0.349	0.371	0.380	0.365
Bitterness	0.026	0.042	-0.035	0.166
Green Char.	0.375	0.386	0.353	0.286
Peach Char.	0.322	0.311	0.253	0.115
Overripe	-0.145	-0.236	-0.263	-0.329

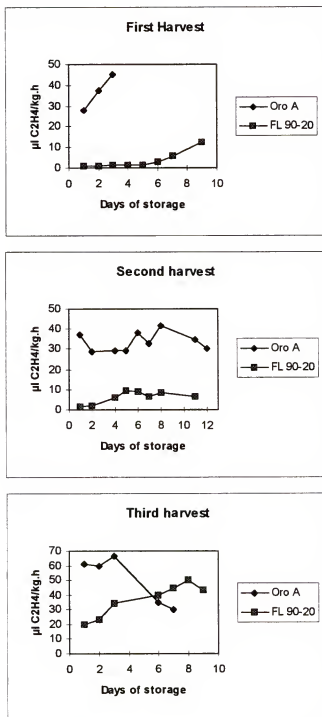


Figure 4-2. Ethylene production at 20C following sequential harvests of 'Oro A' (NMF) and FL 90-20 (MF) (1994)

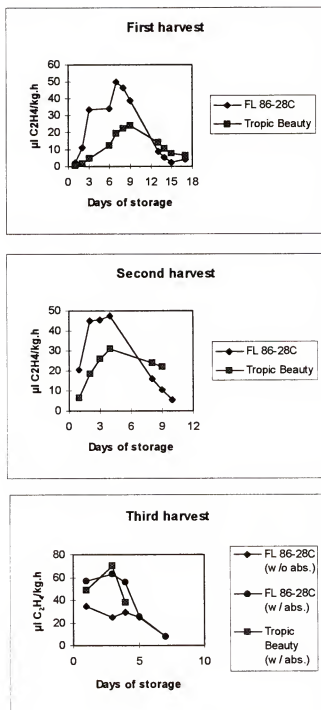


Figure 4-3. Ethylene production at 20°C following sequential harvests of FL 86-28C (NMF) and 'Tropic Beauty'(MF) (1994)

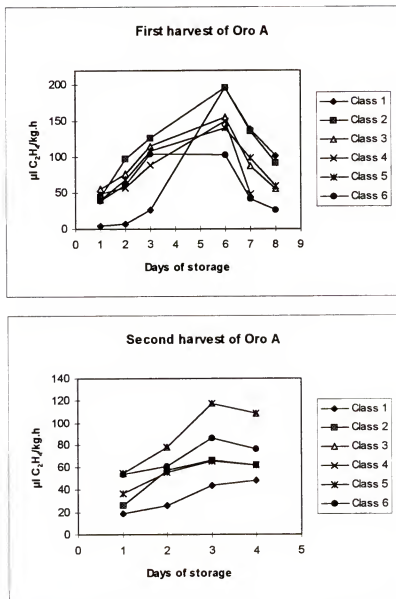


Figure 4-4. Ethylene production at 20C for first and second harvest of 'Oro A'(NMF) (1995)

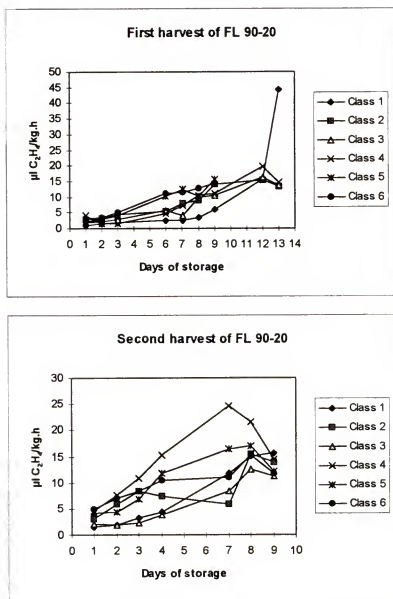


Figure 4-5. Ethylene production at 20C for first and second harvest of FL 90-20 (MF) (1995)

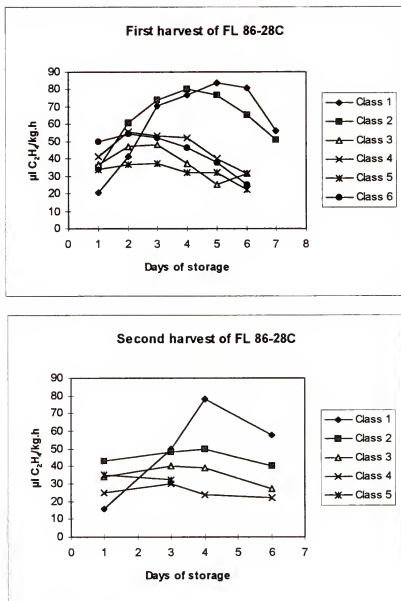


Figure 4-6. Ethylene production at 20C for first and second harvest of FL 86-28C (NMF) (1995)

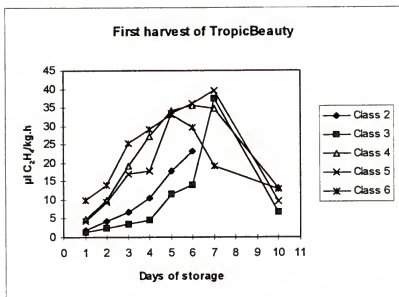


Figure 4-7. Ethylene production at 20C for the first harvest of 'TropicBeauty' (MF) (1995)

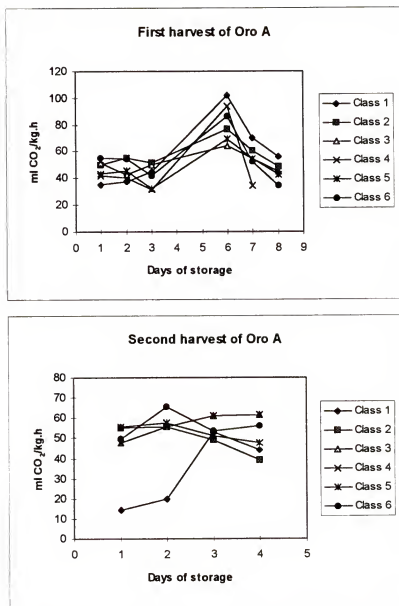


Figure 4-8. Respiration rate at 20C for first and second harvest of 'Oro A'(NMF) (1995)

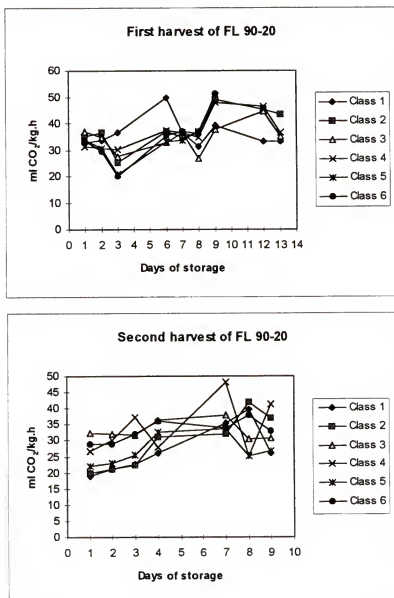


Figure 4-9. Respiration rate at 20C for first and second harvest of FL 90-20 (MF) (1995)

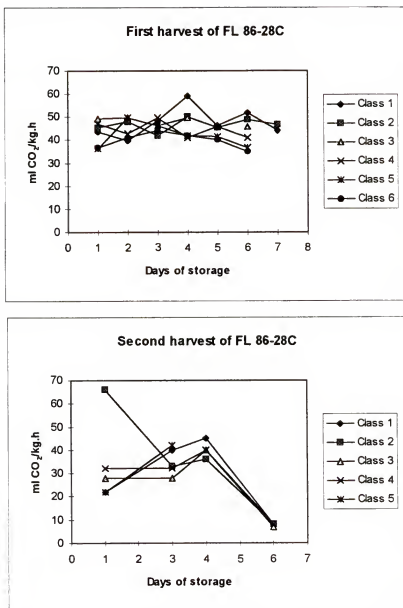


Figure 4-10. Respiration rate at 20C for first and second harvest of FL 86-28C (NMF) (1995)

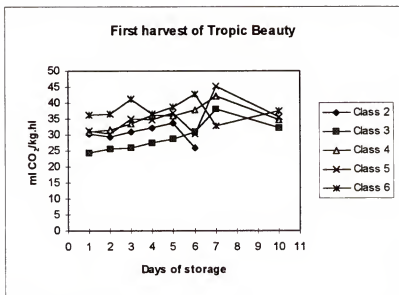


Figure 4-11. Respiration rate at 20C for the first harvest of 'Tropic Beauty'(MF) (1995)

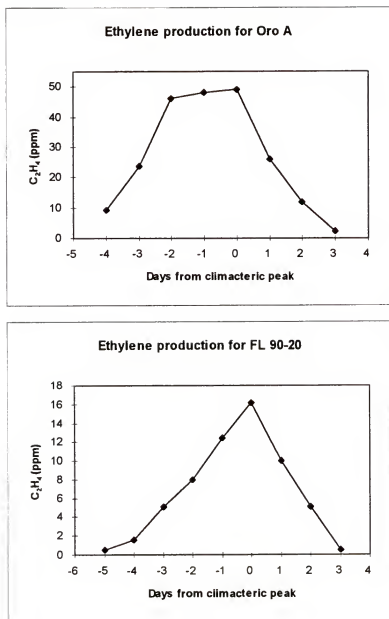


Figure 4-12. Ethylene production for 'Oro A' (NMF) and FL 90-20 (MF) fruit on the tree. Data normalized by averaging peak ethylene production rates of individual fruit ($n=12-16$ for individual symbols)

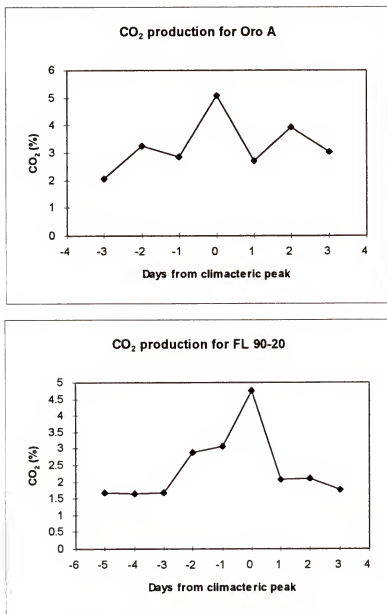


Figure 4-13. CO₂ production for 'Oro A' (NMF) and FL 90-20 (MF) fruit on the tree. Data normalized by averaging peak CO₂ production rates of individual fruit (n=12-16 for individual symbols)

CHAPTER 5 RESPONSE TO POSTHARVEST CHILLING OF MELTING- AND NONMELTING- FLESH PEACH FRUIT

Introduction

Refrigeration is considered a critical need for minimizing physiological deterioration, physical injury, decay, and moisture loss in peaches. However, low-temperature storage is also associated with a serious physiological disorder known as internal breakdown or chilling injury (Ben-Arie et al., 1970; Anderson, 1975). According to Stockwin (1996), internal breakdown is an important reason behind consumer dissatisfaction with California peaches. The incidence of chilling injury in peaches is such that Bruhn (1994) suggested that the industry should explore ways to *guarantee* high quality fruit that has met specific maturity standards and has been monitored during handling with time/temperature indicators. The fruit's stage of maturity is a critical aspect in the development of chilling injury. It has been demonstrated that internal breakdown symptoms are not as severe when peaches are allowed to ripen before cold storage (Ben-Arie and Lavee, 1971).

The extent of chilling injury in peaches is often estimated by the visual classification of the fruit based on the intensity of symptom development (Ben-Arie 1970; Anderson, 1979; Wade, 1981; Retamales et al., 1992). Alternatively, other parameters, such as juice extractability (Ben-Arie and Lavee, 1971; von Mollendorff et al., 1992a), leakage of solutes (Furmanski and Buescher, 1978), and ethylene and CO₂ production

(von Mollendorff and de Villiers, 1988a), have provided an estimation of the magnitude of the chilling injury.

Different peach varieties exhibit variations in propensity to the development of typical chilling injury symptoms, such as flesh translucency or browning, failure to ripen, lack of characteristic aroma, and textural alterations known as mealiness, wooliness and/or leatheriness (Mitchell and Kader, 1989).

Although an association between the development of mealiness and the metabolism of pectic substances has been established, results have differed among researchers. While an activation of pectin-methylesterase (PME) has been reported (Ben-Arie and Lavee, 1971), other authors noted a decrease in the activities of PME (Buescher and Frumanski, 1978) or polygalacturonase (von Mollendorff and de Villiers, 1988b) as a result of a chilling episode. A more recent study by Cantor et al. (1992) emphasized the importance of qualitative changes occurring in the pectin molecule as a result of a chilling exposure. Although the degree of esterification for chilled and non-chilled fruit were comparable, the results pointed to a small region of the pectin molecule that was highly deesterified in fruit that underwent a chilling treatment.

Based on the fact that melting-flesh (MF) and nonmelting-flesh (NMF) peaches differ in their enzymatic capacity for pectic degradation, experiments were conducted to assess the tolerance of cultivars of both groups to internal breakdown symptom development.

Materials and Methods

1995 Study

This study was started in the Spring of 1995 with two selections from the University of Florida Peach Breeding Program. The genotypes studied were the MF selection FL 91-16 and the NMF selection FL 90-47C. Both genotypes are considered late mid- season for Florida growing conditions. The fruit of FL 91-16 is yellow-fleshed, has 70% of skin red blush, and weighs approximately 120 g. The fruit of FL 90-47C is yellow-fleshed, has 30% of skin red blush, and weighs approximately 100 g.

Unripe fruit from each selection were randomly obtained from trees planted at the Teaching Orchard, Horticultural Sciences Department, University of Florida, Gainesville. The harvest date for both selections was June 2, when they appeared to be at a comparable maturity stage. Immediately after harvest, the fruit were separated into five lots. A lot of 48 fruit was selected for the “unripe” evaluation. Another lot of 48 fruit was stored at 20 C for 3 days and was designated “ripe fruit with no chilling exposure.” The other three lots were stored at 4 C and sequentially removed after 1, 2 and 3 weeks of storage, then transferred to 20 C for 3 days, thus representing “ripe fruit with 1, 2 and 3 weeks of storage,” respectively. While the lots for 1 and 2 weeks of storage were comprised of 40 fruit, the lot for 3 weeks of storage had 48 fruit.

Each of the lots of fruit was divided into three groups: 20 fruit were reserved for a visual rating of chilling injury development, the measurement of mesocarp tissue electrical resistance (ER), and the collection of samples for a histological study. Ten fruit were utilized for the determination of extractable juice and ten were reserved for the determination of aroma volatiles. The latter group of ten fruit was frozen as intact fruit at

-20 C for approximately 1 month, at which time the aroma volatile determinations were conducted.

For the visual rating of chilling injury symptoms, fruit were cut in half and evaluated for the development of classic symptoms of meakiness, such as a coarse texture and the dry, stringy appearance of the area of contact between meso- and endocarp. Fruit were classified as either mealy or not mealy. Results were expressed as percentage of mealy fruit.

The ER of the flesh was measured using a Shigometer (Model OZ-86) Electrical Resistance Detector (Osmose Wood Preserving, Buffalo, New York, USA). Measurements were conducted on intact fruit, with a small section of the peel being removed and the probes inserted 1 cm into the flesh. The probes were washed with distilled water and dried between measurements.

Juice extractability was determined following the procedure of von Mollendorff et al. (1992a), in which the volume of juice recovered after centrifuging a peach slurry for 10 minutes at 1,000x g was measured.

For the histological study, blocks of 3mm x 3mm x 5mm were sectioned from the mid-point of the fruit's mesocarp (at the equator and halfway between endo- and exocarp). Specimens were preserved in a fixative composed of 4% glutaraldehyde, 0.2 M dipotassium phosphate, 0.1 M citric acid monohydrate, and 4% glucose at pH 7 (Luza et al., 1992). The choice of this fixative is critical since, based on our experience, mature peach fruit cells fixed with regularly recommended light microscopy fixatives, such as FAA (formalin-acetic acid-alcohol), are especially susceptible to plasmolysis. In order to speed the fixation of the tissue, infiltration of the fixative was promoted by placing the

samples under a slight vacuum for 30 minutes. Before embedding, the specimens were washed in phosphate buffer and transferred every 30 minutes through a series of alcohol dilutions according to the following schedule: (1) 10% ethanol, (2) 25% ethanol, (3) 50% ethanol, (4) 75% ethanol, (5) 50% LRWhite resin/47.5% alcohol//2.5% distilled water, (6) 75% LRWhite resin/23.5% alcohol/1.5% distilled water. Four percent sucrose was added to each of the alcohol dilutions in order to approximate the osmolality of the tissue (Luza et al., 1992). One resin change was carried out before the final embedding in LRWhite resin. Blocks were trimmed, and 2 μ m sections were cut using glass knives on a LKB 3-8800 ultramicrotome (LKB, Bronna, Sweden). For pectin localization, sections were stained in a 0.5% aqueous solution of ruthenium red. Slides were observed using a Labophot-2 light microscope (Nikon, Tokyo, Japan) at 25x and 100x. Photographs were taken using a Microflex UFX-DX photomicrographic attachment (Nikon, Tokyo, Japan).

For the quantitative determination of aroma volatiles, 150 g of fruit mesocarp tissue were homogenized for 2 minutes in a Waring blender and then transferred to centrifuge bottles. Ten ml of methylene chloride containing 5 ppm of pentyl propanoate as an internal standard were added to the homogenate. In order to ease the dispersion of the solvent in the matrix, the bottles were vigorously shaken by hand for 15 seconds and then placed on a wrist-action shaker for 20 minutes. The solvent phase was separated by centrifuging the homogenate for 20 minutes (19,200xg; 5 C) and was subsequently removed from beneath the solid phase by means of a Pasteur pipette. Aliquots (4 ml) of the solvent phase containing the volatile compounds were filtered through 0.45 μ m Teflon syringe filters in order to exclude impurities and transferred to 5-ml vials and sealed with aluminum crimp caps. The analysis was carried out in a Perkin Elmer Gas

Chromatograph-Model 9000 (Norwalk, Connecticut, USA) equipped with an autosampler that injected 1 µl of sample. The system's specifications were as follows: 30 m DB-5 column, 0.32 mm I.D; film 1 µm; split ratio 1:57; constant pressure 25 cm/sec helium carrier gas; flame ionization detector; temperature program: 45 C for 2 min, 3.5 C/min to 230 C, 6 C/min to 265 C, held at 265 C for 10 min; injector temperature: 200 C; detector temperature: 325 C.

The compounds identified were: hexenal, trans-2-hexenal, benzaldehyde, linalool, γ-decalactone, and δ-decalactone. These compounds were selected based on the work of Horvat et al. (1990), who followed the evolution of the major volatiles in peaches according to maturity. The levels of each of the compounds were determined based on standard curves prepared with the authentic compounds (Aldrich Chemicals, Milwaukee, Wisconsin, USA).

Data were analyzed by a one-way analysis of variance with stage of observation and flesh type considered as a treatment. Contrasts of the main effects were used to compare the ripe stage with no chilling exposure with all other stages within MF and NMF types.

A qualitative study of aroma volatiles was conducted using an exit-port sniffing technique (Spencer et al., 1978). The analysis was only carried out with the “unripe,” “ripe with no chilling exposure” and “ripe with 3 weeks of chilling storage” treatments, using extra fruit that had been reserved for this purpose. Sample preparation followed the same procedure used for the quantitative analysis. Analysis was conducted with a Perkin Elmer Gas Chromatograph - Model Sigma 3B (Norwalk, Connecticut, USA), where 1 µl of sample was injected. The system's specifications were as follows: 30 m DB-225

column; 0.25 mm I.D; film 25 μ m; constant pressure 25 cm/sec helium carrier gas; flame ionization detector; oven temperature program: initial temperature: 180 C, ramp rate: 4 C/min to 245 C; held at 245 C for 15 min; injector temperature: 250 C; detector temperature: 325 C. Aromas were sniffed directly from the exit-port sniffing attachment, which was connected to a gas-scrubbing bottle in which air was bubbled through distilled water in order to prevent drying of the nasal membranes while sniffing. Each elution was characterized as it could be associated with a specific aroma and the duration of each elution was timed as an indirect way of quantifying each aroma's intensity.

1996 Study

In the Spring of 1996, the study included three MF genotypes, FL 90-20, FL 90-21W and FL 91-16, and three NMF genotypes, 'Oro A', FL 90-35C and FL 90-47C. FL 90-21W and FL 90-35C are considered mid-season genotypes for Florida growing conditions. The fruit of FL 90-21W is white-fleshed, has 90% of skin red blush, and weighs approximately 95 g. The fruit of FL 90-35C is yellow-fleshed, has 80% of skin red blush, and weighs approximately 100 g. The source of the fruit was the same as in 1995 and harvest dates were May 10 for FL 90-20 and 'Oro A', May 24 for FL 90-21W and FL 90-35C, and May 28 for FL 91-16 and FL 90-47. Pairs of MF and NMF genotypes at a comparable maturity stage were harvested on the same date. Following harvest, all fruit were stored at 4 C. After 1, 2 and 3 weeks of storage, lots of 15, 30, and 15 fruit, respectively, were removed from storage and transferred to 20 C for 3 days to allow the fruit to ripen.

One hour prior to the removal of the fruit from 4 C, and 24 hours after the transfer to the 20 C, the fruit's respiratory and ethylene production rates were measured using a

static system. Instrumentation and procedures were identical to those described in Chapter 4.

After removal from 20 C, 15 fruit were visually evaluated for symptoms of chilling injury and subjected to a cell separation procedure for the estimation of mealiness. Additionally, a subplot of 15 fruit that were stored for 2 weeks at 4 C and then transferred to 20 C, was used for sensory evaluation. In each sensory evaluation session, panelists were presented with fruit with and without a chilling treatment at 4 C. Therefore, a second harvest of 15 unripe fruit per genotype was conducted for all the genotypes 2 weeks after the initial harvest. Fruit from these delayed harvests were also stored at 20 C for 3 days, thus becoming “ripe fruit with no chilling exposure.”

For the visual rating, fruit were cut in half and evaluated for the development of mealiness symptoms. Fruit were rated using a four-point scale with the following categories: “not mealy,” “slightly mealy,” “moderately mealy,” and “severely mealy.” Results were expressed as percentage of fruit in each category.

The procedure of cell separation was that of Ahrens (1989), which had been previously applied to assess variations in fruit mealiness among tomato genotypes. For this procedure, 40 mesocarp disks, 5 mm in diameter and 3 mm in thickness, were cut from five fruit using a cork borer and a razor blade to slice the individual disks. The disks were placed in 30 ml of isotonic (7.48%) sorbitol, as deduced from the work of Luza et al. (1992). Flasks (three per cultivar) were sealed with parafilm and shaken at 100 rpm at room temperature using a gyratory shaker. After 1 hour, 3 ml aliquots of the bathing solution were drawn from each flask and pipetted into cuvettes for spectrophotometric

analysis of the optical density using a Spectronic 20 (Bausch and Lomb, Rochester, New York, USA) at 600 nm (Bartz, 1996). Readings of absorbance were recorded.

For sensory evaluation, the fruit were peeled, sliced, and presented to a trained panel of 10 members who recorded responses on a descriptive 15-point scale ballot (Fig. 5-1). Chilled and non-chilled samples of each genotype were presented side-by-side. A training session where panelists were presented with chilled and non-chilled fruit was conducted prior to the actual sensory evaluations. During this session, panelists defined the sensory notes and their intensities. Two types of attributes were evaluated: texture-related (mealiness, juiciness and hardness) and flavor-related (sweetness, sourness, bitterness, green and peach character, and off-flavor).

For each genotype, the differences in sensory assessments between chilled and non-chilled fruit presented side by side were analyzed according to a split-plot design with panelist as a block effect, variety as a whole plot, and treatment as a subplot. Contrasts of interaction effects were used to determine the significance of the differences. Additionally, chilled MF and NMF fruit presented in separate instances of each session were compared. For this purpose, the data were analyzed according to a randomized complete block design with panelist as a block effect.

Results and Discussion

1995 Study

The visual rating for mealiness development revealed that the NMF selection, FL 90-47C, did not show symptoms of this disorder at any point during the 3-week storage period. On the other hand, the MF selection, FL 91-16, first showed evidence of

mealiness after the second week of storage. There was no further increase in the incidence of mealiness in FL 91-16 fruit after 2 weeks of storage (Table 5-1).

Although the flesh of mealy fruit appeared coarse, the juice extractibility procedure proved ineffective in distinguishing between mealy and normal fruit. In both the MF and the NMF selections, centrifugation following the recommendation of von Mollendorff (1992a) did not produce adequate phase separation and did not allow for juice quantification. When higher speeds/longer times (up to 17,600xg; 20 min) were tried, the volume of juice recovered was similar for mealy and non-mealy fruit.

Results from the ER measurement (Fig. 5-2) in MF fruit followed similar trends to those observed by Furmanski and Buescher (1979) in the cultivars 'Dixired', 'Loring', and 'Redhaven'. Ripening of MF fruit produced a decrease in the flesh ER, which could be attributable to an increase of electrolyte leakage commonly associated with the ripening process. Flesh ER was also depressed after 1 week of chilling plus 3 days at 20 C compared with the levels of unripe fruit. This decrease may have been caused by the increased levels of electrolyte leakage that result from the disruption of membranes due to chilling injury, or possibly ripening, since 1 week was not enough to produce visible symptoms of chilling injury. The peak in ER observed in the MF selection after 2 weeks of storage plus 3 days at 20 C might be due to the binding of ions to the low methoxyl pectic substances that become available after a chilling exposure (Ben-Arie and Lavee, 1971). Dawson et al. (1993) concluded that the high calcium uptake and cation exchange capacity of mealy fruit as opposed to normal fruit were due to the increase in high-molecular weight, partially esterified pectins, which are rich in binding sites and occur in association with mealiness.

While an increase in ER was also observed in NMF fruit following 2 and 3 weeks of chilling exposure, there was no decrease in flesh ER associated with either ripening or the first phase of chilling (Fig. 5-2).

The histological analysis of unripe MF and NMF fruit revealed a fair resemblance between the two types of fruit (Fig. 5-3). Although the contour of the mesocarp cells in NMF fruit tended to be more angular, in both MF and NMF fruit there was an ample range of cell dimensions, and cells appeared turgid, well-structured, and with sharply defined intercellular spaces. The intensity of the ruthenium red stain (shown in the Figures as dark-gray to black tone) between cells of both MF and NMF fruit reflected the integrity of the middle lamella.

In fruit that were ripened without a chilling episode, however, a distinction could be made between the two types of fruit (Fig. 5-4). In MF fruit, cells had undergone separation (dissolution of the middle lamella as evidenced by a lack of stain between the cells) and, frequently, intercellular spaces adopted the form of crevices among cells. Despite cell separation in MF tissue, cell integrity remained uncompromised. In chilled NMF fruit, cells retained good contact among one another, the red stain followed the contour of the cells, and intercellular spaces were more prevalent in the area where more than two cells faced one another.

Likewise, a distinction between MF and NMF fruit could be made in fruit that were ripened after undergoing 3 weeks of storage at 4 C (Fig. 5-5). In MF fruit, which had developed the classical symptoms of mealiness, the most obvious characteristics were a complete lack of staining for pectin and an impressive enlargement of the intercellular spaces to create pockets in certain regions of the tissue. Some of the cells had adopted an

irregular contour. In NMF fruit, although cells had become somewhat more contorted, the general anatomy of the tissue did not differ substantially from that of ripe fruit that had not undergone a chilling episode.

The histological observations validate the different behaviors observed between MF and NMF fruit with regard to their propensity to mealiness development. While the mesocarp of MF fruit was seen to undergo a massive separation of the cells following the chilling offense, the cellular organization of NMF fruit remained almost unaltered from its unripe stage.

An increase in the size of the intercellular spaces of mesocarp cells with chilling injury was also reported by Luza et al. (1992) and von Mollendorff et al. (1992). Based on our staining procedure, no pectin was detected in those spaces. On the other hand, a physical estimation of the internal air space in mealy tissue provides support to our findings. Higher volumes of air space were found in the mesocarp of nectarines that ripened after cold storage as opposed to those ripened with no prior chilling exposure (Harker and Sutherland, 1993; Dawson et al., 1993). Furthermore, a study of chill-injured nectarines based on nuclear magnetic resonance imaging and X-ray computed tomography, revealed the appearance of small and numerous gas inclusions in the mesocarp tissue of mealy nectarine fruit (Sonego et al., 1995).

The quantitative determination of key aroma volatiles revealed changes in the aromatic composition of the fruit as they ripened with and without a prior chilling exposure (Table 5-2). Relevant changes that were observed in both selections when the fruit ripened without a chilling exposure included decreases in the levels of (E)-2-hexenal and benzaldehyde and increases in the levels of γ - and δ -decalactones. Similar changes

upon fruit ripening were noted by Horvat et al. (1990) in the cultivars 'Cresthaven' and 'Monroe'. Working with the cultivar 'Gleason Early Elberta', Do et al. (1969) observed the same trend for both decalactones, but unlike our study, these authors detected an increase in the levels of benzaldehyde with ripening.

The most apparent changes associated with chilling injury were higher levels of (E)-2-hexenal and lower levels of γ - and δ -decalactones in chilled than in non-chilled fruit of both the MF and the NMF selection. In the NMF selection, chilling storage brought about progressive increases in the concentration of hexanal.

In neither type of fruit, the increase in the concentration of (E)-2-hexenal was accentuated after the first week of chilling storage. The extent of the changes in concentration of the decalactones, however, appeared to differ between the selections. After the second week of storage, while the MF selection had shown a significant difference in the levels of both decalactones between non-chilled and chilled fruit, no differences were detected in the NMF selection. Although, after the third week in storage, both selections had reached a highly significant difference in the levels of the decalactones between fruit without and with a chilling episode, the magnitude of the difference appeared to be cultivar-specific. In the MF selection, the concentration of γ -decalactone in chilled fruit after 3 weeks of storage was 59% less than in ripe, non-chilled fruit, and that of δ -decalactone in chilled fruit was 79% less. In the NMF selection, the level of γ -decalactone in chilled fruit after 3 weeks of storage was 48% less than in ripe, non-chilled fruit and, that of δ -decalactone was 45% less.

The sniffing-port technique allowed for the determination of an overall aroma profile for both cultivars (Table 5-3). An indirect way of quantifying each particular smell

was by timing the duration of each elution. Compounds that were perceived for a longer time were presumed to have a more relevant contribution to the overall aroma profile. While the profiles were different for each cultivar, there were some consistencies between them. The “peachy” notes were more noticeable towards the end of the run, indicating the high-boiling point nature of the compounds that contribute to them. A similar observation was made by Spencer et al. (1978) in a characterization of the aroma volatiles of cling peaches. Ripening of both types of fruit without a prior chilling exposure brought about the appearance of “pungent,” “musty/earthy,” and “citrus” notes as well as a decrease in the intensity of the “bitter” notes and an increase in the intensity of the “fruity” and “peachy” notes, as measured based on the duration of their respective elutions. In fruit of both types that were ripened after undergoing a chilling exposure, the “citrus” note was lost and the intensity of the “bitter” note was higher than in the ripe fruit without a chilling exposure. The intensity of the “fruity” and “peachy” notes in the ripe, chilled MF genotype was lower than in ripe, non-chilled MF fruit. In ripe, chilled NMF fruit, this decreasing trend for the “fruity” and “peachy” notes was not as prevalent as in the MF counterpart.

When the duration for all elutions were summed, a conspicuous increase was detected between the green and ripe stages in both selections. Using the profile of the green fruit as a reference, the increase represented an 86% increase in the MF selection FL 91-16 and a 20% increase in the NMF selection. Working with the cultivar ‘Early Gleason Elberta’, Lim and Romani (1963) also noted that maturation had a pronounced effect on the production of volatiles. The smaller increment observed for the NMF selection in this study, however, does not imply a lower value for the NMF ripe fruit, since

at the unripe stage this selection had a much higher value for the summed elutions than the MF counterpart. In fact, the values for the ripe fruit of both selections were comparable.

In contrast, a drop in the sum of all eluted aromas was observed between ripe and chilled fruit. For the MF selection, FL 91-16, and the NMF selection, FL 90-47C, the drop represented 12% and 8% respectively, of the sum of aromas eluted in ripe fruit.

1996 Study

The visual rating for mealiness development in the fruit harvested in 1996 revealed that none of the three NMF genotypes developed mealiness (Fig. 5-6). On the other hand, two of the MF genotypes (FL 90-20 and FL 91-16) had developed mealiness after one week of storage at 4 C and the third MF genotype (FL 91-21W) developed mealiness after two weeks of storage. In general, maximum mealiness development in the MF genotypes took place after the second week in storage, with little increase occurring afterwards.

The cell separation procedure used to assess mealiness in the fruit harvested in 1996 proved to be an effective approach for the objective determination of tissue mealiness (Table 5-4). In all NMF selections, the absorbance of the bathing solution remained fairly stable after 1, 2, and 3 weeks of storage. This would indicate that the number of cells released to the medium was not substantially altered by the length of the chilling exposure of the fruit. On the other hand, in the MF selections FL 90-20 and FL 91-16, where mealiness developed after the first week of storage, the increase observed in the absorbance of the bathing solution could be interpreted as an increase in the number of cells released into the medium. In the MF selection FL 91-21W, however, in which mealiness was in fact observed due to the chilling exposure, no increase in absorbance

could be detected. Due to the fact that this was the only white-fleshed selection, it is likely that the wavelength at which absorbance was being measured (600 nm) was ineffective in the quantification of pigmented cells.

A lateral experiment was conducted to determine if the pattern of cell separation of MF fruit was the same for ripe fruit that underwent chilling and those that did not (Fig. 5-7). The microscopic observation of aliquots of the bathing solution of disks of chilled and non-chilled fruit revealed that while mesocarp cells of non-chilled fruit were generally released individually, mesocarp cells of chilled fruit were released in clumps. This pattern of separation is in agreement with the histological work conducted in 1995. While many cells appeared to have reached a high degree of separation in non-chilled ripe fruit, cell separation was not as extensive in chilled ripe fruit and it occurred mostly in the form of large air pockets among groups or clumps of cells.

The respiration rate at 4 C and 24 hours after transferring the fruit to 20 C is shown in Figure 5-8. While the respiration rate of both MF and NMF genotypes tended to increase slightly with storage time at 4 C, more pronounced rises were observed in the MF selections FL 91-21W and FL 91-16 when fruit were transferred to 20 C after 1, 2, and 3 weeks of storage at 4 C. Conversely, in the NMF genotypes 'Oro A' and FL 90-47C, transfer of the fruit from 4 C to 20 C was associated with decreases in the respiration rate. Although the experimental set-up was different, these results are in contrast with those of von Mollendorff and de Villiers (1988a), who noted that mealiness was associated with a decrease in the respiration rate.

The rate of ethylene production as affected by the chilling exposure is shown in Figure 5-9. A substantial drop in the production of this gas upon removal of the fruit after

2 weeks of storage at 4 C was observed compared to the levels seen after 1 week at 4 C. This decrease can be interpreted as an inhibition in the production of ripening-related ethylene as a result of the chilling offense. It was also noted by von Mollendorff and de Villiers (1988a) that chill-injured peaches had a reduced capability for ethylene production. After the third week, however, four of the genotypes (FL 90-20, 'Oro A', FL 91-21W, and FL 90-35) showed an increase in the production of ethylene. Presumably, the mechanism of synthesis was restored and the release of the gas was resumed. The increased ethylene production after 3 weeks at 4 C in those genotypes may reflect stress ethylene associated with the severe cellular damage related to chilling injury symptom development. As pointed out by Mitchell and Kader (1989), peaches tend to increase in susceptibility to chilling injury as the season progresses and this might explain why the later season selections, FL 91-16 and FL 90-47C, did not recover their ethylene production capability in the latter part of the storage period.

It is worth noting that in all cases, at both 4 and 20 C, NMF peaches had higher rates of ethylene production than MF fruit, which was previously observed in this work with other genotypes of both types of fruit.

The results of the sensory evaluation were expressed in terms of differences between non-chilled and chilled fruit for each genotype expressed in units of the 15-point scale (Table 5-5). The most obvious difference in the response to the chilling exposure occurred in the sensory note "mealiness." Chilled fruit from all three MF genotypes were significantly ($\alpha=0.01$) more "mealy" than non-chilled MF fruit. In NMF genotypes, however, no significant difference in "mealiness" was observed between fruit that did and did not undergo a chilling exposure.

Two out of the three MF selections (FL 91-21W and FL 91-16) were declared significantly ($\alpha=0.01$) less “juicy” after having undergone a chilling exposure. Although the MF selection FL 90-20 was found to be significantly more “mealy” when chilled, no significant loss of “juiciness” was detected due to the chilling exposure. Two of the chilled NMF (‘Oro A’ and FL 90-35C) genotypes were also assessed to be significantly ($\alpha=0.05$) less “juicy” than their non-chilled counterparts.

Similarly, changes in the note “hardness” due to the chilling were affected by the specific genotype, rather than by the type of fruit (MF and NMF). Three out of the six genotypes: the MF selection FL 91-21W and the NMF selections FL 90-35C and FL 90-47C, were found to be significantly “harder” after they had undergone a chilling exposure.

A trend to a decrease in “sweetness” with chilling was primarily observed in MF fruit. Likewise, “sourness” in MF fruit appeared to have also decreased as a result of the chilling exposure. Working at low temperatures below the chilling range, Robertson et al. (1990) reported that, while the titratable acidity of the fruit decreased significantly with storage time, no change was observed in the soluble solids content.

A decrease in the intensity of the “peach character” in chilled fruit was more apparent in the MF genotypes than in the NMF counterparts. The critical involvement of lactones in the typical peach aroma has been reported (Do et al., 1969; Berner, 1991). While a decline in the concentration of γ - and δ -decalactones was observed in both types of fruit as a result of the chilling exposure, the magnitude of the difference between non-chilled and chilled fruit was greater in the MF than in the NMF selection. The decrease in “sweetness”, “sourness”, and “peach character” observed in chilled fruit, particularly in the

MF selections, can be thought to explain the bland flavor often associated with mealy fruit..

Overall, the greatest contrast between MF and NMF fruit occurred in the “mealiness,” “sweetness,” and “peach character” notes. While chilled MF fruit were scored as significantly more mealy, less sweet, and with less peach character than non-chilled fruit, no major difference in those notes occurred between non-chilled and chilled NMF fruit. On the other hand, chilled fruit of both MF and NMF types were scored as significantly less juicy and harder than non-chilled fruit (Table 5-6).

The differences between MF and NMF chilled fruit for genotype pairs harvested on the same date and presented in the same session are shown in Table 5-7. The most consistent difference between the two types of fruit was in the note “mealiness,” for which all MF genotypes were scored higher than NMF types, and in the note “hardness,” for which all NMF genotypes were scored higher than their MF counterparts.

Panelist Name..... Date..... Sample Code.....

Texture

Mealiness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Not Mealy													Very Mealy	

Hardness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Very Soft													Very Hard	

Juiciness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Very Dry													Very Juicy	

Flavor

Sweetness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Not Sweet													Very Sweet	

Sourness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Not Sour													Very Sour	

Bitterness

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Not Bitter													Very Bitter	

Green Character

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Not Green												High Green Character		

Peach Flavor

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No Peach Flavor												High Peach Flavor		

Off-Flavor

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No Off-Flavor												High Off-Flavor		

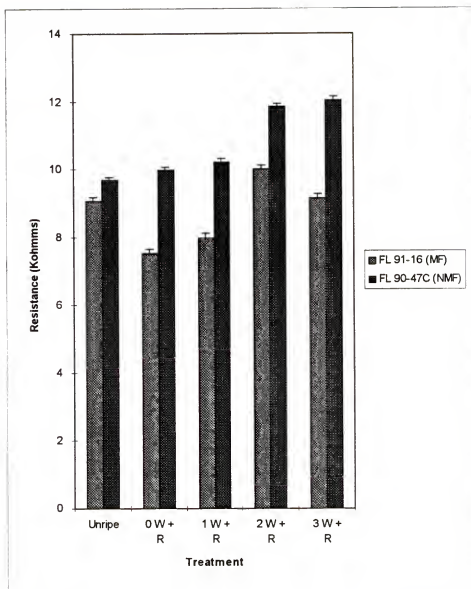
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Figure 5-1. Form used for the descriptive sensory evaluation of chilling injury

Table 5-1. Percentage of mealy fruit in 1995 (n=20)

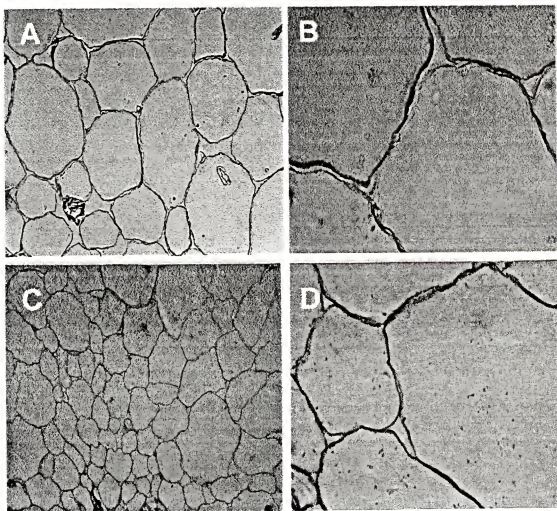
Genotype	Unripe	0 W+R	2W+R	3W+R
FL 91-16 (MF)	0	0	62	58
FL 90-47C (NMF)	0	0	0	0

Treatments: 0 W + R: no storage at 4 C and 3-day ripening at 20 C; 1 W + R: 1-week storage at 4 C and 3-day ripening at 20 C; 2 W + R: 2-week storage at 4 C and 3-day ripening at 20 C; 3 W + R: 3 week-storage at 4 C and 3-day ripening at 20 C



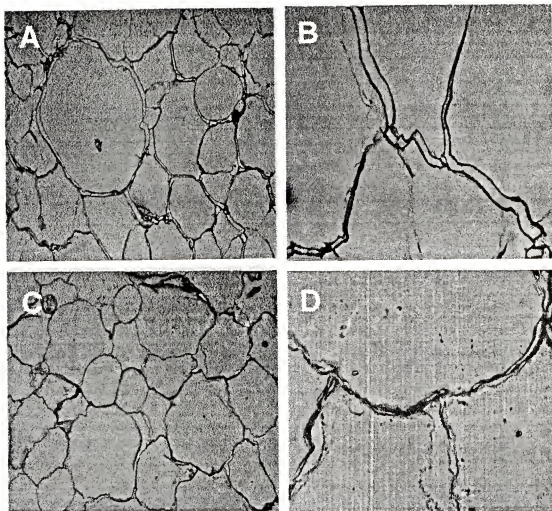
Treatments: 0 W + R: no storage at 4 C and 3-day ripening at 20 C; 1 W + R: 1-week storage at 4 C and 3-day ripening at 20 C; 2 W + R: 2-week storage at 4 C and 3-day ripening at 20 C; 3 W + R: 3 week-storage at 4 C and 3-day ripening at 20 C. Bars represent standard error.

Figure 5-2. Flesh electrical resistance before and during storage and ripening



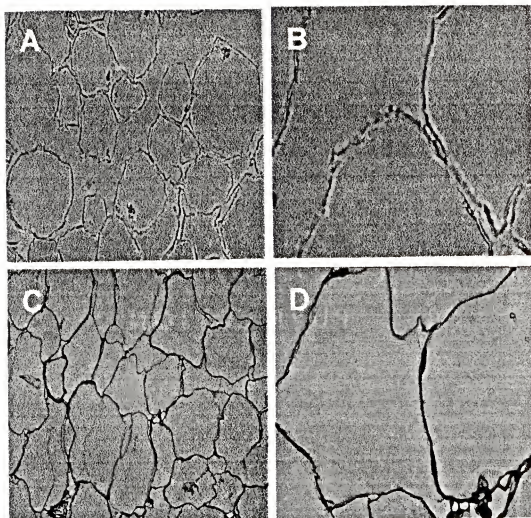
MF fruit at 25x (A) and 100x (B) NMF fruit at 25x (C) and 100x (D)

Figure 5-3. Mesocarp cells of unripe MF and NMF fruit



MF fruit at 25x (A) and 100x (B) NMF fruit at 25x (C) and 100x (D)

Figure 5-4. Mesocarp cells of ripe, non-chilled MF and NMF fruit



MF fruit at 25x (A) and 100x (B) NMF fruit at 25x (C) and 100x (D)

Figure 5-5. Mesocarp cells of chilled and further ripened MF and NMF fruit

Table 5-2. Concentration (ppm) of five major aroma volatiles in peach

Genotype	Treatment	Linalool	Hexanal	(E)-2-hexenal	Benzaldehyde	γ -Decalactone	δ -Decalactone
FL 91-16 (MF)	Unripe	0.35**	0.24	0.26**	0.19*	0.25**	0.12**
	0W+R	1.38	0.25	0.19	0.17	1.19	0.51
	1W+R	0.90	0.27	0.26**	0.21*	0.95*	0.56
	2W+R	0.93	0.27	0.26**	0.17	0.82**	0.29*
	3W+R	0.82	0.27	0.26**	0.18	0.49**	0.11**
FL 90-47C (NMF)	Unripe	1.55	0.25*	0.26**	0.23**	0.31**	0.24**
	0W+R	1.27	0.22	0.10	0.19	1.35	0.60
	1W+R	0.89	0.26**	0.27**	0.19	0.92*	0.68
	2W+R	0.92	0.28**	0.26**	0.22	1.22	0.55
	3W+R	0.79	0.29**	0.26**	0.21	0.70**	0.33**

Treatments: 0 W + R: no storage at 4 C and 3-day ripening at 20 C; 1 W + R: 1-week storage at 4 C and 3-day ripening at 20 C; 2 W + R: 2-week storage at 4 C and 3-day ripening at 20 C; 3 W + R: 3 week-storage at 4 C and 3-day ripening at 20 C

* Significantly different from the 0 W + R concentration within the column at the 95% level

** Significantly different from the 0 W + R concentration within the column at the 99% level

Table 5-3. Aroma volatiles qualitative analysis using exit-port sniffing

Genotype	Smell	Elusion Duration (secs.)		
		Unripe	0W+R	3W+R
FL 91-16 (MF)	pungent	0	3	2
	musty/earthy	0	3	5
	citrus	0	2	0
	fruity	29	58	50
	fruity	0	4	0
	peachy	2	2	2
	fruity	33	45	44
	bitter	30	9	37
	peachy	47	58	56
	fruity	12	27	23
	fruity	5	16	6
	fruity	9	11	9
	fruity	3	21	12
	peachy	15	41	38
	peachy	3	7	14
	Summation	159	296	261
FL 90-47C (NMF)	adhesive	0	4	3
	musty/earthy	0	4	2
	citrus	0	2	0
	fruity	59	63	59
	peachy	3	2	2
	fruity	70	55	51
	bitter	57	23	42
	peachy	36	70	62
	fruity	25	19	22
	fruity	17	34	14
	fruity	10	13	17
	peachy	39	32	40
	peachy	6	17	15
	Summation	264	316	289

0W+R: no storage at 4 C and 3-day ripening at 20 C

3W+R: 3-week storage at 4 C and 3 day-ripening at 20 C

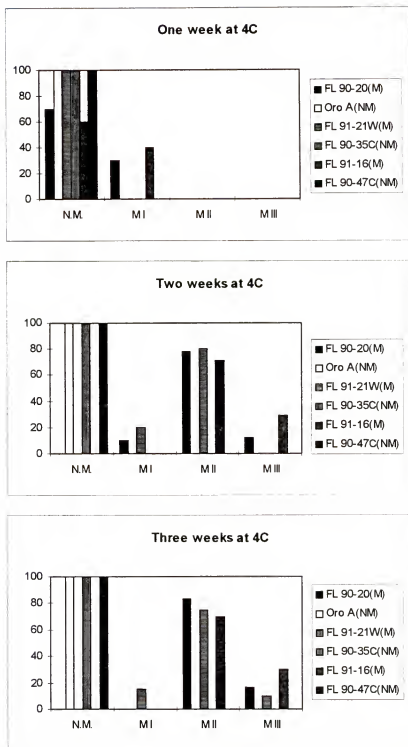


Figure 5-6. Percentage of mealy fruit in 1996 (n=15)

Table 5-4. Absorbance (600 nm) of bathing solution of tissue disks after 1 hour of incubation

Genotype	Storage time			
	1 week	2 weeks	2 W	3 weeks
FL 90-20 (MF)	0.09+/- 0.002	0.13+/- 0.007		0.19+/- 0.002
FL 91-21W (MF)	0.06+/- 0.001	0.05+/- 0.002		0.05+/- 0.001
FL 91-16 (MF)	0.07+/- 0.000	0.12+/- 0.003		0.21+/- 0.008
Oro A (NMF)	0.05+/- 0.000	0.05+/- 0.000		0.07+/- 0.001
FL 90-35C (NMF)	0.08+/- 0.001	0.08+/- 0.001		0.07+/- 0.000
FL 90-47C (NMF)	0.07+/- 0.001	0.06+/- 0.000		0.07+/- 0.000

⁽¹⁾ Averages of 3 replicates and standard errors

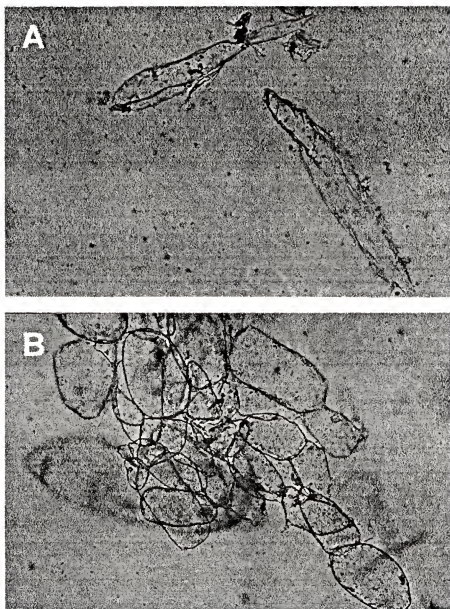


Figure 5-7. Pattern of cell separation in ripe non-mealy (A) and mealy (B) MF fruit

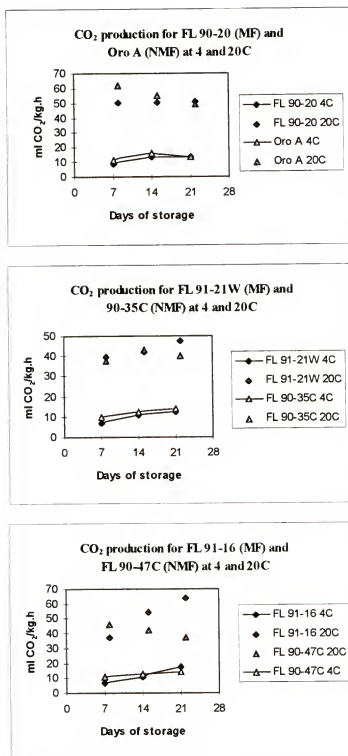


Figure 5-8. Respiration rate after 1, 2 and 3 weeks at 4 C and 24 h after transfer to 20 C

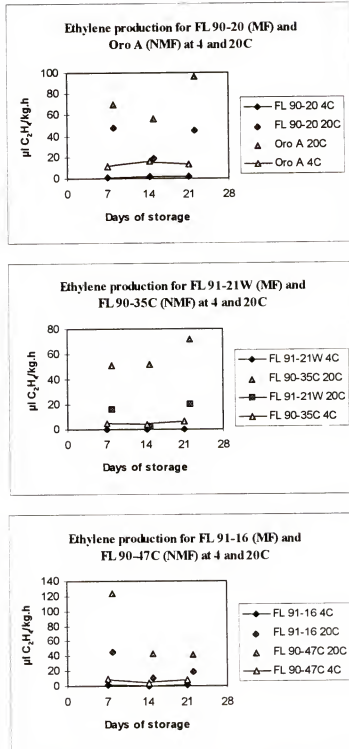


Figure 5-9. Ethylene production after 1, 2 and 3 weeks at 4 C and 24 h after transfer to 20 C

Table 5-5. Sensory difference⁽¹⁾ between non-chilled and chilled fruit for the individual genotypes

Genotype	Meatiness	Hardness	Juiciness	Sweetness	Sourness	Bitterness	Green char.	Peach char.	Off-flavor
FL 90-20 (MF)	-3.7**	-0.3	1.7	1	1.5*	0.2	0.9	1.3	-2.2*
FL 91-21W (MF)	-5.5**	-4**	7.2**	1.5	0	-1	-0.8	2.6*	-1.5
FL 91-16 (MF)	-7.2**	-1.1	6.1**	2.7**	1.6*	-0.3	-0.4	3.7**	0.1
Oro A (NMF)	-0.1	-0.9	2.2*	-0.6	0.8	-0.2	0.1	0.1	1.7
FL 90-35C (NMF)	-0.5	-2.8**	2.8*	1.4	-0.6	-2.8**	-1.8*	2.1	-4.5**
FL 90-47C (NMF)	0	-3.5**	0.4	0.4	-1.1	-0.3	-0.2	-0.8	0.1

⁽¹⁾ Expressed in units of the 15-point scale. Differences between non-chilled and chilled fruit significant at $\alpha=0.05$ (*) or $\alpha=0.01$ (**)Table 5-6. Average sensory difference⁽¹⁾ between non-chilled and chilled MF and NMF fruit

Genotype	Meatiness	Hardness	Juiciness	Sweetness	Sourness	Bitterness	Green char.	Peach char.	Off-flavor
Melting Flesh	-5.4**	-1.8**	4.9**	1.7**	1*	-0.3	-0.1	2.5**	-1.1
Nonmelting Flesh	-0.2	-2.4**	1.8**	0.5	-0.3	-1.1	-0.6	0.4	-0.8

⁽¹⁾ Expressed in units of the 15-point scale. Differences between non-chilled and chilled fruit significant at $\alpha=0.05$ (*) or $\alpha=0.01$ (**)Table 5-7. Sensory difference⁽¹⁾ between MF and NMF chilled fruit for genotype pairs presented in the same session

Genotype pairs (MF - NMF)	Meatiness	Hardness	Juiciness	Sweetness	Sourness	Bitterness	Green char.	Peach char.	Off-flavor
FL 90-20 - Oro A	4.9**	-8.4**	3.7**	-0.3	0.7	-0.5	-1.2	0.4	1.3
FL 91-21W - FL 90-35C	4.7*	-3.7	-0.7	0.2	1.0	-2.5	-1.5	1.0	-3.8*
FL 91-16 - FL 90-47C	7.3**	-6.1**	-3.8**	-1.0	-1.1	0.1	-0.2	-2.7**	0.4

⁽¹⁾ Expressed in units of the 15-point scale. Differences between MF and NMF fruit significant at $\alpha=0.05$ (*) or $\alpha=0.01$ (**)

CHAPTER 6

SUMMARY AND CONCLUSIONS

Quality Comparison between Melting- and Nonmelting- Flesh Genotypes

The sensory ratings for the different MF (FL 90-20 and ‘TropicBeauty’) and NMF (‘Oro A’ and FL 86-28C) genotypes in 1994 show that clear differences in the textural aspects of the fruit were detected between the two types of genotypes, with the NMF fruit being “harder,” less “juicy,” and more “rubbery” than their MF counterparts. However, no grouping of the genotypes in any of the flavor notes could be established based on their flesh type (MF/NMF).

The first three principal components resulting from the principal component analysis of the 1994 sensory data explained 64% of the total variability. The factor loadings for PC1 showed that all of the textural notes, “hardness,” “juiciness,” and “rubberiness,” had large impacts on its definition. It is also evident that a contrast can be defined between “sweetness,” “peach character,” and “overripe” and the rest of the sensory notes.

The graphic representation of the principal component results as affected by the genotype revealed a clear distinction between the overall sensory assessments for MF and NMF fruit. Based on the importance of the textural notes in PC1, separate principal component analyses were conducted for the textural and flavor notes.

While the graphic representation of the textural principal components also revealed a separation between MF and NMF fruit, no distinction between the two types of fruit

could be established based on the flavor notes. Likewise, the chemical analysis showed that while differences in pH, titratable acidity, and soluble solids were detected in the four genotypes analyzed, no consistent grouping could be made based on the MF/NMF nature of the fruit.

In 1995, a high proportion (40%) of the total variation in the sensory data was explained by the first principal component. An analysis of the factor loadings of PC1 revealed that the most pronounced contrast occurred between the “overripe” trait and the rest of the notes, indicating an opposing behavior of these notes and the “overripe” note in the definition of PC1.

As in 1994, the graphic depiction of the principal component analysis conducted on the 1995 sensory data sorted by genotype showed that a distinction could be established between the textural aspects of MF and NMF fruit, but not between their flavor aspects.

When sensory results were sorted by harvest and diameter class rather than by genotype, the principal component analysis revealed a special clustering of the results suggesting that there may be a relationship between fruit diameter and the sensory aspects of the fruit, which may weaken as maturation continues on the tree.

Developmental Aspects and Potential Maturity Indices of Selected Melting- and Nonmelting-Flesh Genotypes

Based on the increase of the fruit diameter on the tree as well as on the average diameter of harvested fruit, it was deduced that fruit of the NMF genotypes ‘Oro A’ and FL 86-28C are able to complete normal development off the plant even if they have not reached full size.

In 1994, fruit developmental aspects for the above mentioned genotypes were based on their variation with sequential harvests. Significant decreases in titratable acidity and increases in pH and the soluble solids:titratable acidity ratio were observed in both NMF genotypes with maturation.

The production of ethylene 24 h after harvest showed a rising trend with sequential harvests in both genotypes. The color parameters L^* and hue angle tended to decrease with maturation in the peel ground color (GC) as well as in the cheek (CH) and blossom-end (BE) flesh. In FL 86-28C, the hue angle at the BE was consistently lower than at the CH. A significant decrease in firmness with maturation was observed in fruit of both genotypes. In FL 86-28C, firmness at the BE end was higher than at the CH region of the fruit.

In 1995, developmental aspects of the MF genotypes FL 90-20 and 'TropicBeauty' and the NMF genotypes 'Oro A' and FL 86-28C were related to changes associated with fruit diameter and harvest date. The pH and the soluble solids:titratable acidity ratio tended to increase and the titratable acidity tended to decrease with increasing diameter and later harvests in all four genotypes.

Although the levels of ethylene production measured 24 h after harvest tended to increase with increasing diameter and later harvest in all four genotypes, the NMF genotypes produced consistently higher levels than their MF counterparts. The respiration rate measured 24 h after harvest was not as impressively affected by either the harvest date or the fruit's diameter. Neither did those rates appear to differ greatly between MF and NMF fruit.

The most prevalent trend in the color parameters in 1995 was a decrease in the hue angle in all the regions measured and all four genotypes. As in 1994, the hue angle in the CH flesh was consistently larger than at the BE. Significant decreases in both CH and BE firmness were detected in all four genotypes with increasing diameter and later harvests. As expected, this drop in firmness was much more impressive in MF genotypes than in their NMF counterparts. As in 1994, for a given harvest-diameter class, firmness at the BE was generally higher than at the CH region of the fruit.

Individual linear correlations were conducted between each genotype's fruit attributes at harvest and their respective PC1 values. Following are the three attributes that best correlated with PC1, and thus are promising maturity indices: for FL 90-20: peel hue, peel L, and CH texture; for TropicBeauty: peel L, CH texture, and BE texture; for Oro A: CH texture, BE texture, and CH chroma; for 86-28C: BE texture, CH hue, and CH texture. The fact that BE and CH texture were highly correlated with sensory PC1s in all four genotypes, demonstrates the importance of texture as a potential maturity index, even in NMF genotypes, where decreases in flesh firmness with maturation are not as impressive as in MF types.

The pattern of ethylene production over time for fruit harvested in 1994 reflects the different developmental stages at which the fruit were harvested. Fruit from the first harvest were at either the climacteric rise ('Oro A') or the preclimacteric phase (FL 90-20), fruit from the second harvest were soon to reach the climacteric peak ('Oro A') or the climacteric rise (FL 90-20), and fruit from the third harvest were entering their postclimacteric phase ('Oro A') or reaching their climacteric peak (FL 90-20). The pattern of ethylene production was also a reflection of the developmental stage in the FL

86-28C and 'TropicBeauty' fruit. These genotypes, however, appeared to be more synchronized in their development than 'Oro A' and FL 90-20.

As in 1994, the pattern of ethylene production for fruit harvested in 1995 was a good indicator of the developmental stage of the fruit at harvest. In general terms, fruit from the second harvest, whether MF or NMF, were at a more advanced phase in their ethylene production pattern than those from the first harvest. It would also appear that when the differences in initial ethylene production rates among diameter grades were considerable, those differences were maintained throughout the fruit's ethylene production cycle. As in 1994, the rates of ethylene production were much higher in the NMF genotypes than in their MF counterparts.

The relationship between the respiratory drift and the fruit's developmental stage in both 1994 and 1995 was similar to that observed for ethylene production. In general, fruit from the second harvest appeared to be in a more advanced phase of their respiratory drift than those from the first harvest.

Ethylene production for fruit on the tree in 1995, followed a climacteric pattern for both 'Oro A' and FL 90-20, with levels in the NMF genotype being much higher than those in the MF genotypes. As for the CO₂ production on the plant, both genotypes exhibited climacteric behavior and both had similar rates of CO₂ production. Unlike the production of ethylene, which showed a clear climacteric trend, the production of CO₂ of individual fruit tended to oscillate more.

Response to Postharvest Chilling of Melting- and Nonmelting-Flesh Genotypes

The response to postharvest chilling was assessed after storing the fruit for 1, 2 and 3 weeks at 4 C, and further allowing it to ripen for 3 days at 20C. The visual rating for mealiness conducted in 1995 revealed that while the NMF selection FL 90-47C did not develop mealiness at any point during the three-week storage period, the MF FL 91-16 selection had developed this disorder after the second week of storage. Flesh electrical resistance (ER) measurements for unripe MF fruit decreased with ripening, regardless of whether the fruit had or had not received 1 week of chilling prior to ripening, and peaked after 2 weeks of chilling plus ripening. While a rise in ER was also observed in NMF fruit following 2 and 3 weeks of chilling exposure, there was no decrease in flesh ER associated with either ripening or the first week of chilling.

The histological study revealed that while no clear distinction was evident between unripe MF and NMF fruit, in ripe MF fruit, mesocarp cells had reached a degree of separation not observable in ripe NMF fruit. While an impressive expansion of the intercellular spaces was observed in MF fruit with a chilling exposure prior to ripening, the low-temperature storage did not result in a major anatomical disruption in NMF fruit.

The quantitative determination of key aroma volatiles revealed an increase in the levels of γ - and δ -decalactones and a decrease in benzaldehyde in both MF and NMF fruit with ripening. The most apparent changes observed in both selections with chilling injury were an increase in the level of (E)-2-hexenal and a decrease in the levels of γ - and δ -decalactones. However, the extent of the decrease in both decalactones was less significant for the NMF selection.

The sniffing-port technique revealed that ripening of both types of fruit without a prior chilling exposure brought about the appearance of “pungent,” “musty/earthy,” and “citrus” notes as well as a decrease in the intensity of the “bitter” notes and an increase in the intensity of the “fruity” and “peachy” notes. In fruit of both types that were ripened after undergoing a chilling exposure, no “citrus” note was observed and the intensity of the “bitter” note was greater than in the ripe fruit without a chilling exposure. The summation of the duration of all elutions increased from unripe to ripe fruit in both selections, but dropped between ripe and chilled fruit (12% less for MF fruit and 8% less for NMF fruit).

The visual rating for mealiness conducted in 1996 reinforced the notion that the MF genotypes (FL 90-20, FL 90-21, and FL 91-16) developed visible mealiness in 1 or 2 weeks at 4 C depending on the genotype, whereas the NMF genotypes (‘Oro A’, FL 90-35C, and FL 90-47C) did not show evidence of this disorder at any point during the course of the 3-week storage trial.

The cell separation procedure demonstrated that in the MF selections, where mealiness had become evident, cells were released to the medium as a consequence of the chilling damage. Conversely, in the NMF genotypes, no major increase in the number of cells released to the bathing solution was observed due to chilling.

Unlike NMF fruit, the MF selections FL 90-20 and FL 91-16, both of which showed severe mealiness development, showed a decrease in the respiration rate due to chilling. A drop in the rate of ethylene production was also observed in both MF and NMF genotypes when chilled. For the genotypes ‘Oro A’, FL 90-20, FL 91-21W, and FL 90-25, the ethylene levels rose again after the second week of storage at 4C.

The biggest contrast in the sensory assessment of MF and NMF fruit with regard to chilling storage occurred in the “mealiness,” “sweetness,” and “peach character” notes. While chilled MF fruit were scored as significantly more “mealy,” less “sweet,” and with less “peach character” than non-chilled fruit, no major difference in those notes occurred between non-chilled and chilled NMF fruit. On the other hand, chilled fruit of both MF and NMF types were scored as significantly less “juicy” and “harder” than non-chilled fruit.

The contrast between the sensory profiles of chilled MF and NMF fruit showed that the most consistent difference between the two types of fruit was in the “mealiness” note for which all MF genotypes were scored higher than NMF types, and in the note “hardness” note, for which all NMF genotypes were scored higher than their MF counterparts.

Conclusions

Based on the quality comparison, it was concluded that the inclusion of the NMF trait did not compromise peach fruit flavor in the genotypes studied, thus validating an important breeding objective. It remains to be seen, however, whether the textural attributes characteristic of NMF fruit will gain consumer acceptance.

The maturity index study revealed that BE and CH texture were consistently meaningful in both MF and NMF types. Color parameters were also important predictors of the sensory judgements. Ideally, both texture and color can serve as practical maturity indices for the fruit pickers. The next step in this research should involve the definition of

threshold values in the selected maturity index. As with any maturity index, it is crucial to evaluate its efficacy in numerous harvesting seasons, before it is recommended to growers. Based on the response of the different MF and NMF genotypes to postharvest chilling, it was determined that, unlike MF genotypes, which developed symptoms of mealiness in 1 or 2 weeks at 4 C, the NMF genotypes did not show evidence of this disorder at any point during the 3-week storage period. This observation was confirmed histologically. Chilling of MF fruit brought about an impressive expansion of the intercellular spaces in mesocarp tissue, but did not affect NMF fruit. The condition observed in chilled MF fruit can be related to the ease with which cells are released to the medium in the cell separation procedure. Based on the difference in the degree of mealiness development observed between MF and NMF in response to postharvest chilling, it would be meaningful to explore the metabolism of pectic compounds in relation to a chilling offense.

Sensory evaluation to assess the response to postharvest chilling showed that while chilled MF fruit were scored as significantly more “mealy,” less “sweet,” and with less “peach character” than non-chilled fruit, no major differences in those notes occurred between chilled and non-chilled NMF fruit. On the other hand, chilled fruit of both MF and NMF types were scored as significantly less “juicy” and “harder” than non-chilled fruit. The substantial loss of “peach character” occurring in MF genotypes upon chilling, could be substantiated by the finding that γ - and δ - decalactones, which are essential to the peach aroma, were lost to a greater extent in chilled MF fruit than in their NMF counterpart. These results suggest that chilling injury will be less of a concern in fresh market NMF cultivars than in MF peaches. Taken together with the likelihood that NMF peaches will be more amenable to handling at the tree-ripe stage than MF peaches, NMF

cultivars appear to present an outstanding prospect for improved fresh quality for the consumer.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


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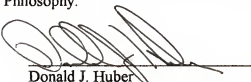
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